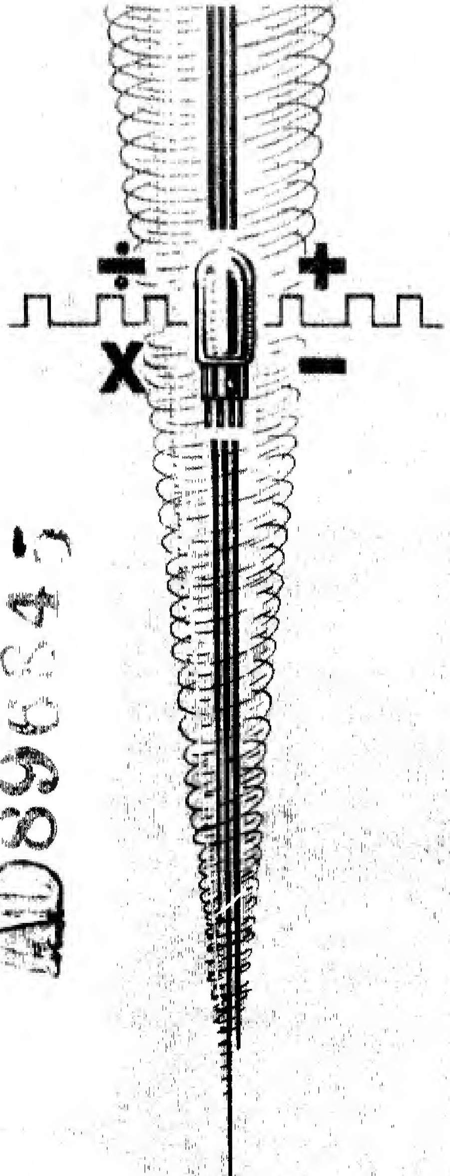
AD NUMBER: AD0896845
LIMITATION CHANGES
TO: Approved for public release; distribution is unlimited.
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 1 Nov 1947. Other requests shall be referred to the Office of Naval Research, Washington, DC 20360.
AUTHORITY
ONR ltr dtd 9 Nov 1977

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.



1

PROJECT WHIRLWIND

Contract N5ori60

SUMMARY REPORT NO. 2

VOLUME 2

THE WHIRLWIND PROGRAM
(PART II)

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SPECIAL DEVICES CENTER

M-166

P. 1 of 6

1

PROJECT WHIRLWIND

Summary Report. No. 2

November, 1947

112p.

Project Whirlwind. Volume 2.

THE WHIRLWIND PROGRAM, PART II

Volume 2 of 22 Volumes

Contract N5ori60

Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

220 076

Summary Report No. 2

Authors of material for which credit is not given in the various reports and memorandums.

Jay W. Forrester

Robert R. Everett

Harris Fahnestock

Prof. Philip Franklin

Hugh R. Boyd

David R. Brown

George G. Hoberg

C. Robert Wieser

Outlines and Editing:	Prof. J. N. Ulman
	Perry Crawford, SDC
Printing and Assembly:	John C. Proctor

Foreword

Summary Report No. 2

Volume 2

Volume 2 of this report is a continuation of material in Volume 1.

M-165

Table of Contents

Volume 2

Illustration List

Volume 2

Illustration List, Continued

Volume 2

REFERENCE INDEX

M Series Memorandums

REF.	VOL.	REF.	VOL.	REF.	VOL.
M-32	8	M-95	8	M-133	18
M-46	9	M-96	9	M-134	7
M-56	9	M-99	15	M-135	7
M-58	15	M-100	8	M-136	7
M-61	8	M-101	11	M-137	7
M-62	4	M-103	16	M-138	15
M-63	4	M-105	19	M-140	4
M-64	4	M-106	11	M-141	7
M-65	14	M-107	19	M-142	8
M-66	4	M-109	16	M-143	9
M-68	15	M-110	15	M-144	10
M-69	4	M-111	7	M-145	11
M-71	8	M-112	9	M-146	12
M-72	16	M-113	7	M-147	13
M-74	14	M-114	19	M-148	14
M-76	4	M-116	16	M-149	15
M-77	15	M-117	7	M-150	16
M-78	8	M-118	16	M-151	17
M-80	16	M-119	16	M-152	18
M-81	16	M-121	9	M-153	19
M-82	16	M-123	7	M-154	20
M-83	16	M-124	8	M-155	21
M-85	14	M-127	7	M-156	22
M-89	11	M-128	16	M-157	11
M-91	15	M-129	7	M-158	7
M-92	15	M-130	9	M-159	9
M-94	8	M-131	16	M-160	8
		M-132	16	M-161	7

REFERENCE INDEX

E Series Memorandums

C Series Memorandum

REF.	VOL.	REF.	VOL.
E-7	14	E-52	19
E-24	7	E-53	13
E-31	10	E-54	19
E-32	10	E-55	19
E-33	19	E-56	15
E-37	15	E-57	15
E-38	19	E-58	19
E-39	15	E-59	19
E-41	15	E-60	19
E-42	15	E-61	16
E-44	19	E-63	19
E-45	19	E-64	15
E-47	15	E-68	13
E-48	19	E-69	15
E-49	19	E-71	19
E-50	16	E-73	16

C-15	14

REFERENCE INDEX

R Series Memorandums

REF.	VOL.
R-36	14
R-49	14
R-63	14
R-64	3
R-89	19
R-90	4
R-94	14
R-98	14
R-100	14
R-103	14
R-104	16
R-106	15
R-108	15
R-109	19
R-110	9
R-111	15
R-113	15
R-114	8

REF.	VOL.
R-115	4
R-116	4
R-117	16
R-118	16
R-120	10
R-121	19
R-122	18
R-123	17
R-124	11
R-125	14
R-126	19
R-127	5
R-127	6
R-128	10
R-129	12
R-130	9
R-131	10
R-132	10

7.0 Mathematics

The original mathematical work on Project Whirlwind was started in the early part of 1946, and constituted an investigation of methods of interpolation and integration to be used in the airplane stability and control problem. The results of this study were used in the programming of the aircraft problem which is reported in Volume 14, C-15. Dr. Loud investigated the stability of the numerical solutions proposed for the airplane problem. (See Volume 8.)

The project's mathematics work is under the guidance of Professor Franklin of the M.I.T. Mathematics Department. The mathematics program under Professor Franklin is discussed in the remainder of this section. This material has been extracted from his memorandum M-160, in Volume 8.

7.1 The Mathematics Program

The projected Whirlwind high-speed electronic digital computer, from the mathematical point of view, has several objectives. One aim is to solve the equations of motion of aircraft and so serve as the computing element of an aircraft analyzer. A more general objective is the solution of other simulation and control problems of engineering interest, particularly in the field of dynamics and ordinary differential equations.

The mathematical studies in the past have related to specific equations of interest, some tests of existing numerical methods, and attempts to anticipate and overcome possible difficulties. At present a study of known methods of solving simultaneous linear equations and differential equations is under way, with a view to the coding of such methods for the computer. These studies will be extended to other problems listed in Section 7.3.

7.2 Studies Already Completed

A survey of numerical methods made by Dr. Loud and his associates, summarized in Volume 6, M-61, revealed as subjects of major importance the solution of linear simultaneous equations, and the solution of ordinary differential equations.

For the solution of linear simultaneous equations, elimination methods, iteration methods, relaxation methods, matrix methods, and the method of steepest descent have all been considered and expositions for these methods studied. For some of these, codes are in process of preparation.

The errors inherent in solving systems of equations of very high order, when all of the coefficients have random errors, has been pointed out.

A number of solutions have been carried out for simple differential equations to provide case histories of accumulated round-off and truncation errors. These indicate the objections to numerical integration over a large number of cycles without some check, such as the use of the energy integral for conservative systems. The possibility of filtering out frequencies corresponding to computational instability terms has also been considered.

A method of using Fourier Transforms to estimate the best value of a function or its derivative (the message) when its values over a long range are known only to within certain random errors (noise) was presented to the group. Later studies indicated this as having restricted application to computation because of the rare occurrence of data with truly random errors.

Last year several conferences were held at M.I.T. on digital computation. Some were sessions of the Electrical

Engineering Department seminar, but were well attended by representatives of the Mathematics Department and Project Whirlwind. Another series of smaller conferences were attended by some electrical engineers, including Professors Hazen and Y. W. Lee, as well as several members of the Center of Analysis. The mathematicians present included Professors Phillips, Martin, Wiener, Franklin, Wallman, and Thomas.

In addition to these men other M.I.T. staff members have shown an interest in electronic computers, and a willingness to give advice when problems in their special fields are considered. Thus, if shock waves are under consideration, advice can be obtained from Professors Tsien or Liu, or Dr. Kopal, who are all familiar with this field. For elasticity problems and their theory Professor Reissner, for statistical and meteorological applications Professor Wadsworth, and for general numerical computation Professors Hitchcock, Crout, and Hildebrand are available.

The many members of the M.I.T. Mathematics Department who are interested in numerical computation contribute much information about recent developments through informal discussions.

In addition, the staff members of the project have attended meetings at Princeton, Philadelphia, New Haven, and Cambridge, at which computing methods were discussed. The group has followed recent developments in the theory of codes and numerical computation at Princeton, Harvard, the University of Pennsylvania, and elsewhere.

7.3 Plan for Future Investigations

Certain problems of interest to applied scientists and engineers can be most conveniently solved by numerical methods. Classified mathematically, the principal types are as follows:

1. Solution of ordinary differential equations with given initial conditions.

2. Solution of parabolic and hyperbolic partial differential equations, obtaining the characteristic curves as in 1.

3. Solution of systems of linear simultaneous equations.

4. Solution of ordinary differential equations with boundary conditions at more than one point.

5. Solution of elliptic partial differential equations for various types of conditions on the boundary of a region.

6. Solution of non-linear simultaneous equations.

7. Least square solutions of overdetermined systems of the types of 3 and 6.

8. Solution of integral equations.

9. Tabulation of functions.

While the relative advantages of different methods may change in the transition from hand or desk calculations to high-speed machines, it is improbable that any radically new mathematical principles will come into play. Much past and recent experience bears this out.

Thus, the methods used by Aiken in computing tables, or by the Watson Laboratory in checking the moon's motion, bear strong resemblance to those long known to astronomers, and except for the use of conditional orders the methods used for elementary functions, such as those coded for the A.R.C. by Booth and Britten, would have been used by Babbage in the 19th Century if he had completed his analytical engine.

Again, the report on linear equations by Bargmann, Montgomery, and von Neumann recommends as the two best methods an iteration rule, stated by Hotelling, which amounts to an application of Newton's method of approximation, or an elimination method which is that used by most computers in such forms as those of Doolittle or Crout.

And except for minor details of technique, the differential analyzer uses mathematical methods differing little from those used by Kelvin in evaluating special integrals with his globe, disk, and cylinder integrator.

This suggests that the first attack with the computer on the problems listed above should be by processes close to the traditional ones. Of course, two special points to be covered in taking over existing methods are the coding of complete instructions to remove any human judgment, and keeping the high speed from letting us carry the computations beyond their range of validity.

Study is planned for each of the categories listed above. Comments on the attack planned on each of these categories will be found in Professor Franklin's memorandum M-160, Volume 8.

In addition to general methods, several aspects of the specific application of the computer to the analysis and control problem will be considered. Thus, the detailed equations and constants for different types of surface and air craft will be investigated.

Some preliminary studies of statistical correlation of radar data at information centers will be continued.

7.4 The Practical Estimate of Error

While existence theorems are nice to have when they can

be obtained, much numerical work proceeds successfully without them. For example, astronomers guessed right on semi-convergent asymptotic series before they were understood by the purists. Series with coefficients obtained by numerical methods are used to predict the moon's position years in advance, but the stability of the system of sun, earth, and moon under the known initial conditions has never been established with complete mathematical rigor. Many of the iteration processes used to find roots of equations can either converge or diverge rapidly. By comparing, say, a fourth and a fifth approximation, and sensing the size of the discrepancy, a computer can be programmed to recognize the process as finished, promising for further approximations, or useless for computation because of divergence or excessively slow convergence.

A large percentage of recent numerical computation for partial differential equations has no other justification than that the results seem to converge. Undoubtedly many WWI and WWII solutions will use such evidence, for lack of anything better.

Because of the labor of making codes, high-speed machines will be chiefly used for whole fields of solutions. A certain amount of experiment on the machine may be needed at the start, but once verified for a few cases, the method will extend to the whole field.

Similar considerations apply to formulas for the size of the error. These are seldom used literally, because if rigorous they are apt to be much too pessimistic in practice. At best such formulas are merely useful to prove convergence; a comparison of successive values then estimates the error.

These comments should not be construed to mean that no study is being made of errors in numerical computation. Such studies are being given great importance, but it is the feeling of the Project that much of its work must be performed without rigorous estimates of errors.

7.5 The Influence of Mathematics on the Design of Whirlwind I

The specifications for Whirlwind I were set up with the aim of providing a prototype capable of performing all the operations desired from a computer, on a scale large enough to be applied to many typical situations, and sufficiently limited to be constructable in reasonable time. However, within this last limitation it was found feasible to provide for greater speed and storage capacity than any existing digital computer possesses.

The types of desired mathematical operations are fairly well known; namely, the four fundamental arithmetic operations, and certain logical operations such as shifting, digit transfers, sub-programming, and conditional sub-programming. From these fundamental elements any finite combination of computational processes can be built up.

The mathematician's requirement is that these operations be performed either directly or by combination of other operations. Thus division or square rooting can be either built in as special operations or carried out by a sub-program. The present plans call for a built-in division unit. Also, a few special orders enable the operator to call for any particular sub-program, square root for example, as easily as though it were a built-in operation.

Considerable study of binary arithmetic and the conversion problem showed the feasibility and advantage of having the computer work in binary arithmetic but translate data and outputs from or into the decimal notation.

A guiding principle of the Whirlwind I specifications has been maximum flexibility. This will simplify the extension to larger models, and will increase the effective power of the

computer, for example by allowing an arbitrary distribution of the storage capacity between numbers and orders.

Beyond the fundamental questions just mentioned, and verification that the computer has sufficient speed and capacity for certain specific problems such as that of aircraft control, mathematical considerations can have little effect on the basic design.

With regard to overall capacity of later models, experience with Whirlwind I and theoretical considerations can only dictate ratios of components, rather than absolute size. For the size at any stage will always be limited by economic and engineering factors. Any machine is certain to have just a little less capacity than that required for some desired applications. For Whirlwind I, sufficient capacity has been provided for preliminary investigation of aircraft analysis and for complete treatment of other control and simulation problems.

8.0 Training

Present progress on high-speed electronic digital computers will make equipment available on a production basis much faster than personnel is being trained. It is therefore necessary that a well-rounded computer development center undertake a training program. Successful execution of a training program depends on availability of computing equipment similar to that going studied. Although preliminary training in mathematical methods and computing system design can be done without operating equipment, an operating system must be available for laboratory work in the later stages of training. Furthermore it is difficult to build up the required enthusiasm for a training course without actual equipment. The expected availability of the Whirlwind I computer within a year and a half has stimulated consideration of a training program at M.I.T.

The M.I.T. Electrical Engineering Graduate School at present trains men in computers as part of their work toward an advanced degree in Electrical Engineering. The Graduate School quota at the present time permits sixteen Project Whirlwind staff members to work toward advanced degrees while holding full-time research appointments with the Electrical Engineering Department. The man on an academic research appointment spends full time on Project Whirlwind research work except for the six hours per week devoted to attending classes. The man completes his academic program with an advanced degree, with a background of electrical engineering and mathematical subjects, and with the experience gained in actual laboratory work on a computer program. At the same time these men make important contributions to the Project Whirlwind work. (See Volume 12 on Input and Output Devices, Volume 17 on High-speed Switching, and Volume 18 on Pulse Transformers.)

In addition to the regular academic program for staff members of the Project, the thesis research done by members of the

Electrical Engineering Department teaching staff and by full-time graduate students is often made a part of the Project Whirlwind basic research studies. The Project has provided the equipment and laboratory facilities for several thesis studies in which the work is closely associated with the subject of simulation or computation. Examples of such thesis research are the iconoscope and pulsed-light studies of Volumes 20, 21 and 22.

The first step toward extending the M.I.T. curriculum in digital computation has been an expansion of courses in the Electrical Engineering Department, Center of Analysis. Professor S. H. Caldwell and Professor Richard Taylor with Mr. Frank Verzuh and others have extended the academic work of the Center of Analysis to include greater emphasis on digital computation and to provide elementary laboratory work in this field.

Courses in many departments of M.I.T. contribute directly to the application of digital computers in their respective fields. Attention is now given to numerical analysis in several courses within the Mathematics Department. It is probable that for a well-rounded program certain courses should be organized specifically with high-speed computing equipment in mind. Memorandum M-61 in Volume 8 by Dr. Loud discusses Mathematical Training in more detail.

Beginning in November 1947, Project Whirlwind will conduct a course meeting two hours per week. This course is primarily for training Project Whirlwind staff members, several of whom are new to the program and unfamiliar with the field as a whole. Staff members from other departments at M.I.T. will be invited to attend. The course will continue until available material has been covered. The block diagrams of the Whirlwind system will be treated in detail, as will electronic circuits and the components of the Whirlwind system. In the field of problem coding, the greatest stress will be placed on problems of simulation and control.

The training program which will be conducted this year by Project Whirlwind will be recorded and transcribed and should provide an excellent basis for a formal academic course in the future.

A training program in digital computation should include preparation of people for mathematical research; problem set-up, coding, and machine operation; computing machine development; and machine maintenance.

A. Mathematical Research

Persons well founded in all phases of mathematics must be available to formulate new problems as they arise in terms of the proper mathematical concepts. These people must also search for more accurate and more efficient ways of executing problems which can be solved by presently available means. Research is necessary in the errors arising in numerical computation and in the existence of solutions. High-speed computers will open up new possibilities in the field of statistical research where highly trained personnel will be required.

B. Mathematical Formulation and Problem Setup

Many of the problems presented for machine solution have been studied and are reasonably well understood. Men with a good mathematical background and an understanding of the potentialities of large-scale computers must be available for reducing problems to a form which can be handled by computing equipment. Ability and imagination in this field will be essential to effective use of

simulation and control equipment. People from all scientific fields should be drawn into computer training. It is felt that the use of large-scale computers can be readily mastered by anyone with a good scientific background. Widespread application of computers can come only through appreciation of the capabilities of computers by people in all fields of scientific activity.

C. Computing Machine Development

For many years to come, computers will require improvement and redesign. They must be reduced in size and simplified. Mobile and even portable digital equipment can be used. Those working in machine design must know mathematics, electronics, system engineering, and production practices.

D. Maintenance

Beginning at least one year prior to the delivery of computing equipment to a new location, an adequate training program must be set up for maintenance personnel. As discussed elsewhere, computing machines must incorporate extensive facilities for error indication and trouble shooting, but even so, the equipment is complex and the training of well qualified maintenance personnel must not be overlooked.

It is recommended that the Government agencies having use for high-speed digital computing equipment take immediate steps to train personnel, as outlined above. Such training might be arranged on the same basis as presently used for the M.I.T. Radar School and the postgraduate training of Army and Navy officers.

9.0 Engineering Time Distribution

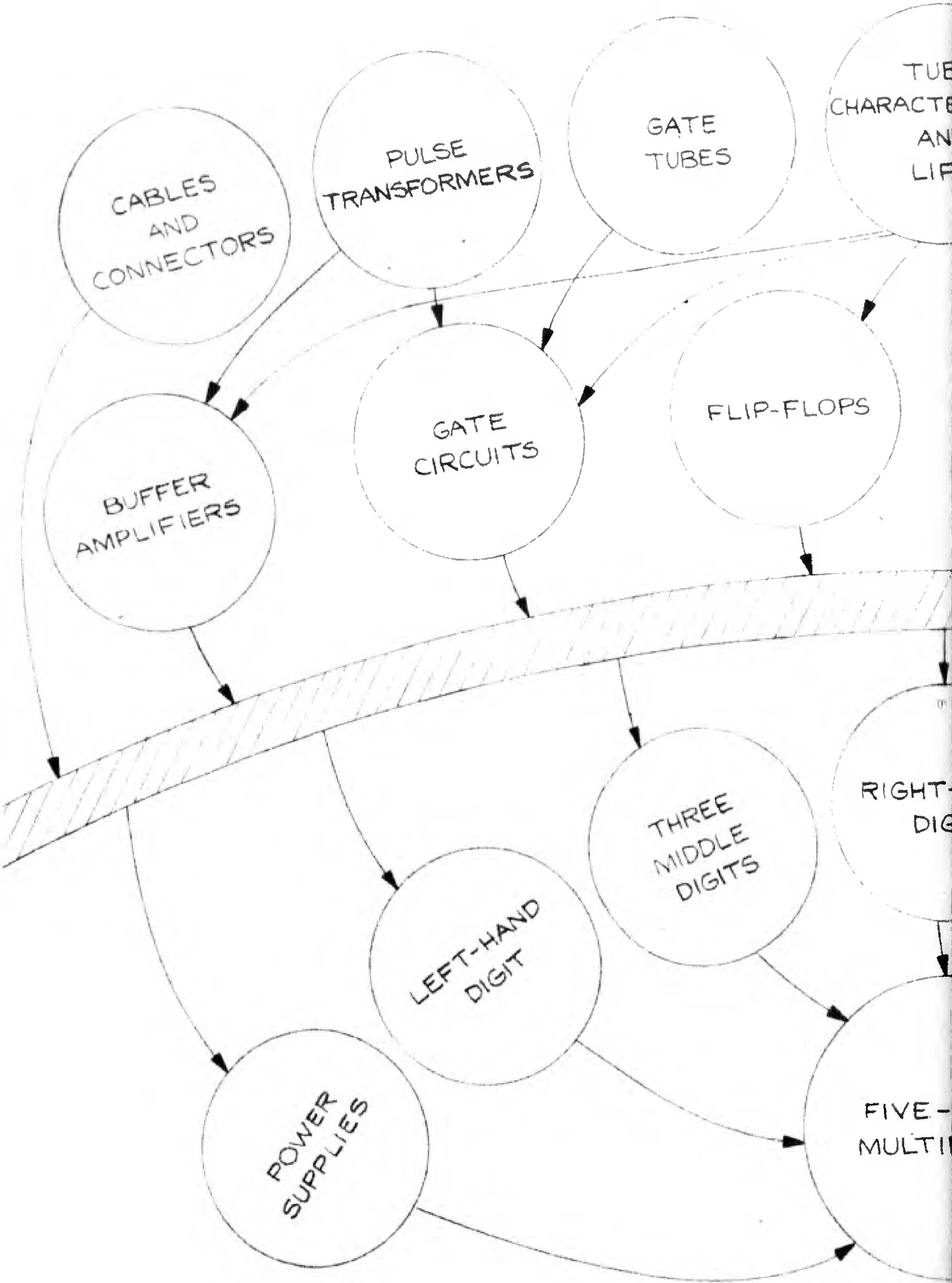
Drawings B-31204 and B-31205 have been included to illustrate the magnitude of the engineering effort which lies between a block diagram or a design study, and a final operating computer system. The engineering phases of the arithmetic element are illustrated in Drawing B-31204. These correspond to steps 2 through 7 of the 10 steps in Section 4.0. The outer activities are of a basic research nature where components are studied and developed. Results of the applied research are then used in design of a final system. The illustration converges to a 5-digit multiplier built for systems testing purposes. Similar flow diagrams could be drawn for other elements of the computer and for the complete computer.

Drawing B-31205 shows activities converging into a complete simulator or control system. The computer, although the most complex, is only one element of the complete system. Research groups must plan the simulator system including computer, mathematical formulation of problems, human response studies, displays and recording, and output actuators. These actuators may be switches, or output servo systems.

The following section illustrates the preceding comments by giving specific figures on distribution of staff time for Project Whirlwind.

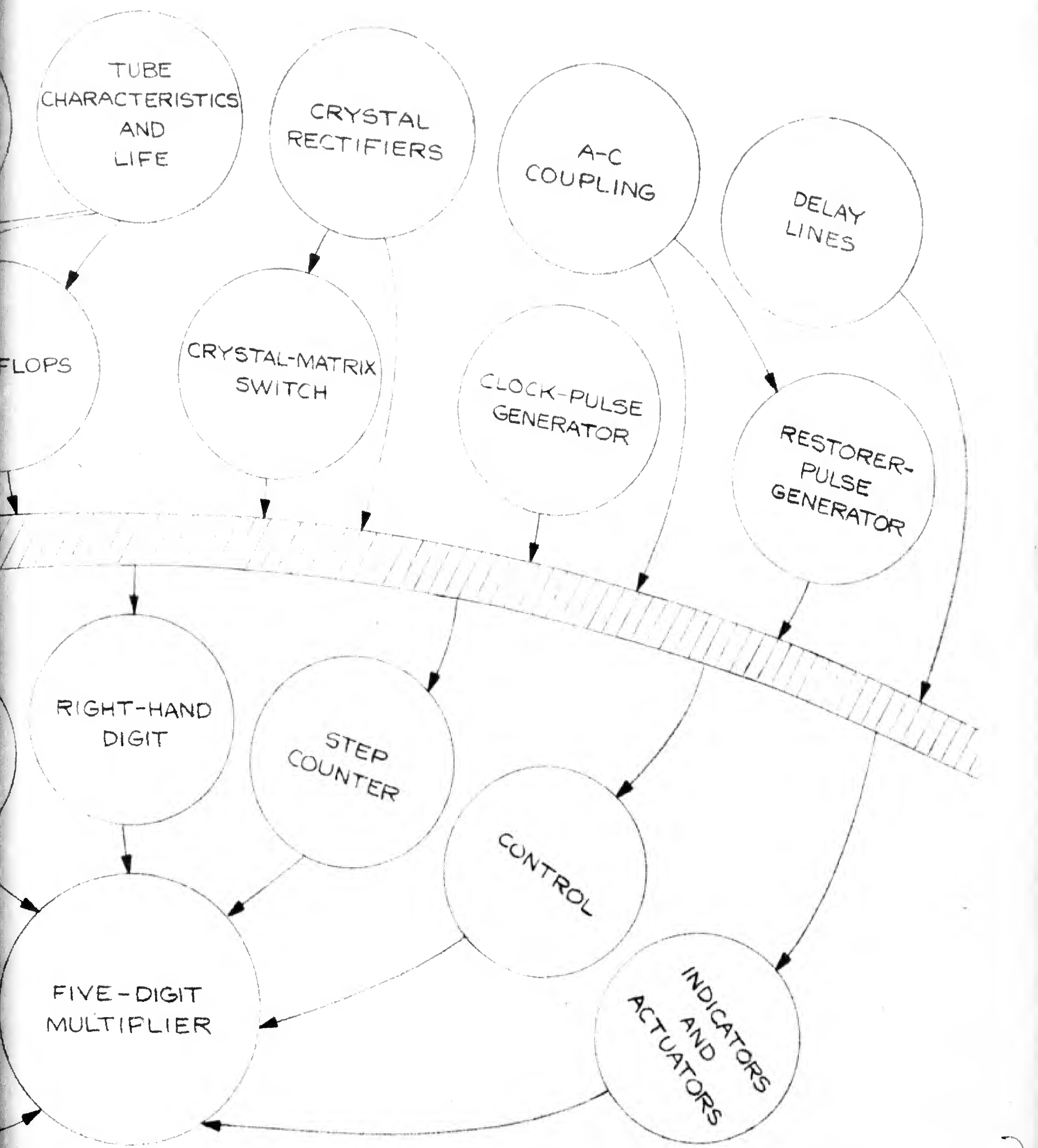
9.1 Staff Time Distribution

This is an analysis of the distribution of effort by the Whirlwind staff on the various phases of the work done to bring the computer to the stage of development described by the block diagrams in Volumes 5, 6 and 7; by the aircraft equations in Volume 14; and by the electrical system drawings in Volume 13. This analysis covers the period of November 1945 to November 1947. It does not include the work done in



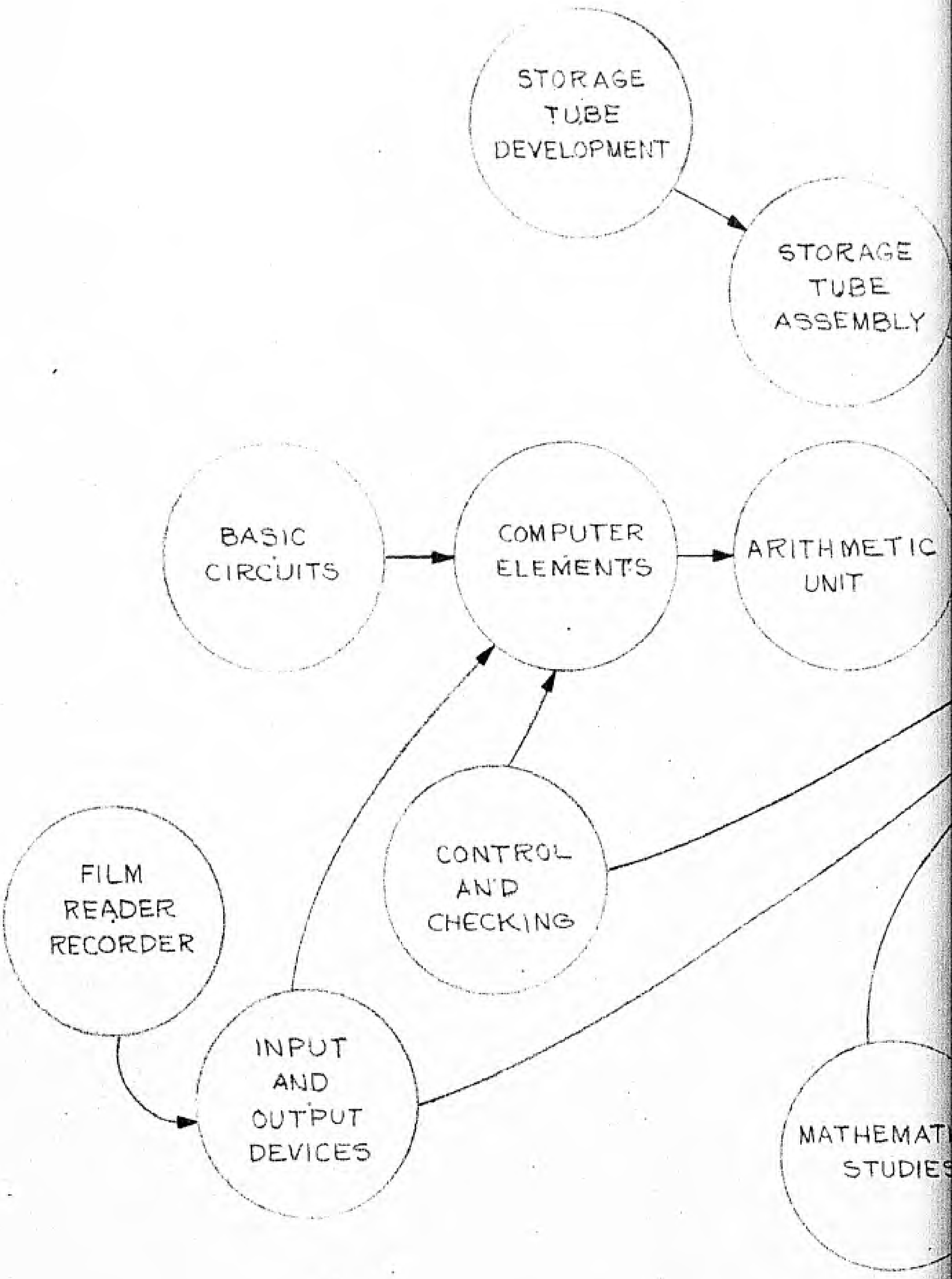
PHASES OF DEVELOPMENT O

B-31204



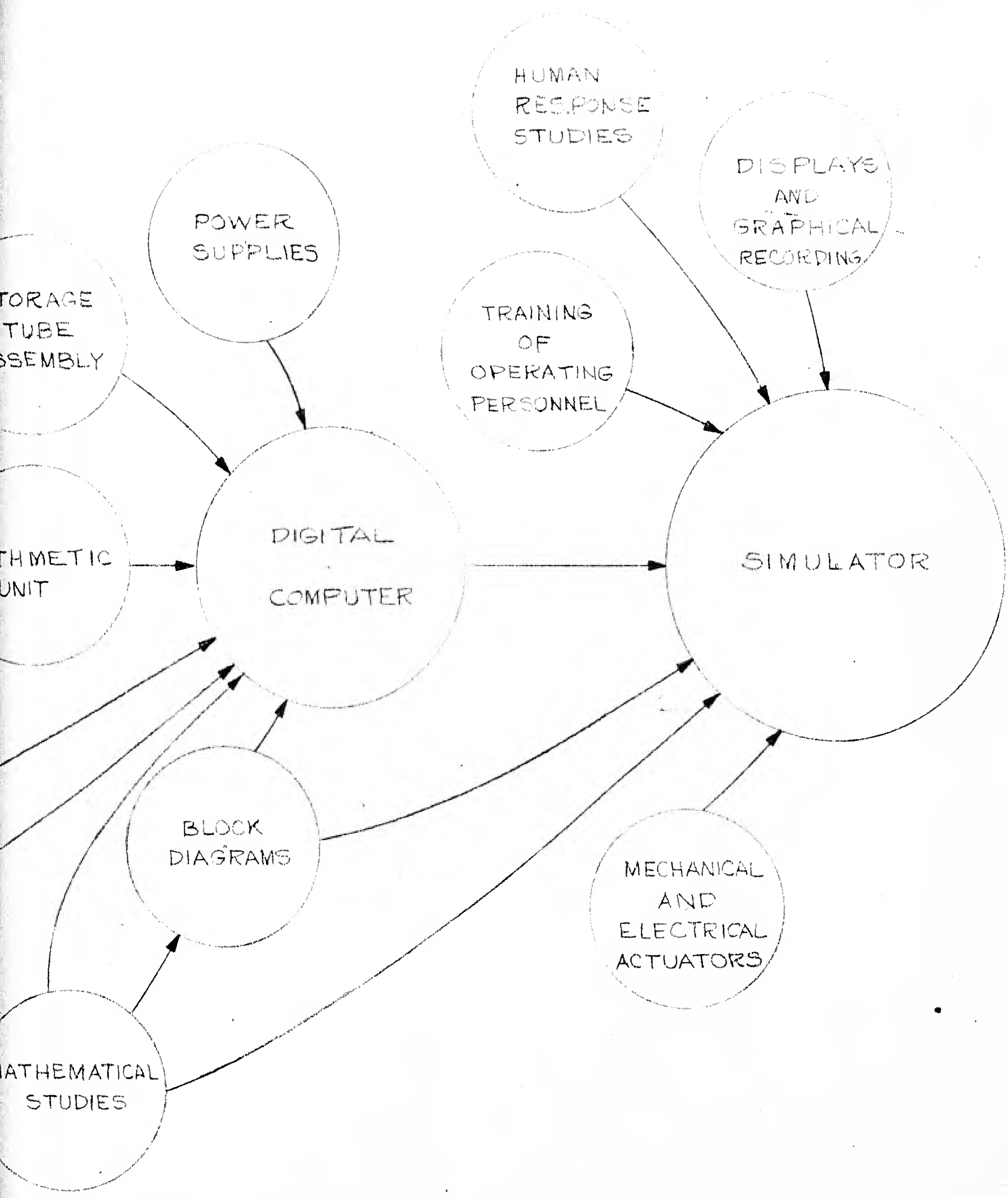
ENT OF THE FIVE-DIGIT MULTIPLIER

B-31204



SIMULATOR D

B-31025



R DEVELOPMENT

B-31205

comparing analogue and digital methods which resulted in the decision to build a digital computer. Omitted also is the time spent during the period covered by this report on input and output devices by the Eastman Kodak Company, and on design and construction of electronic equipment by Sylvania Electric Products, Inc. The staff work reported herein has been supplemented by the work of draftsmen, wind tunnel technicians, and electronic technicians varying from 15 to 40 people during the period.

Figures in the following tables give man-months of staff engineering time and the percentages of total time devoted to various phases of the computer program. The Summary in Table I shows that of the total time of 558 man-months, 14% was devoted to administration; 20% to the aircraft equations, mathematical analysis, and block diagrams; and the remaining 66% to engineering. Table II is a more detailed time breakdown of the above summary.

Some comments on what is included under the various headings will be given to avoid misunderstanding since the terminology in the field of computation is not consistent.

Under the heading of aircraft equations are included (1) the setting up of the equations of motion of an aircraft in a form involving coefficients which can be experimentally determined (Volume 3, R-64); (2) determining these variable coefficients (Volume 14, R-98); (3) determining the number of points which must be stored to give an adequate representation of the coefficients (Volume 14, R-103); (4) formulating a step-by-step procedure for solving these equations; (5) coding the procedure for the computer and (6) determining scale factors.

Under mathematics are included investigations in the field of step-by-step solutions, interpolation and integration methods, and other subjects necessary for, but not limited to, the specific aircraft problem. These subjects are reported in Volume 8.

The block diagram work reported in Volumes 5, 6 and 7, involves no electronic work. The block diagram group consults with the electronic engineers to determine if a proposed scheme is technically feasible from an electrical circuit or timing point of view, and in such cases the time of both the block diagram men and the electronics men has been charged to block diagrams. Also charged to block diagrams, as far as possible, is the time spent by any electronic engineers or supervisors in studying the block diagrams to insure that the operations therein described are adequately designed and built into the system. Work on aircraft equations, mathematics, and block diagrams has occupied 20% of the staff time.

The figure of 17% of staff time on storage (Volumes 9 and 10) is quite accurate, since the greatest part of the work has been done by a group who have not been concerned with other parts of the computer. The subdivisions of storage into research, construction, and test are somewhat arbitrary but appear reasonable. The research program of the storage tube group has been greatly accelerated by our ability to frequently consult with and draw on the rich experience of Professor Nottingham of the Physics Department, Professor Harris of the Chemistry Department, and Professor Breckenridge of Electrical Engineering Department. Their time, of course, does not appear in this summary.

The electronics effort, exclusive of storage, input, output, conversion, and technical supervision, amounts to 34% of

the total. Where to draw the line between circuits (Volumes 15 through 19) and the system (Volume 13) is somewhat open to question. We believe that a very large number of tubes and circuits must be put together before the appearance of the troubles inherent in systems rather than circuits. For example, the 32-position switch (Volume 17, R-123), which consists of flip-flop circuits, gate circuits, and drivers, containing 57 tubes and 180 crystal diodes, is not yet considered or assigned to systems design and test.

TABLE I

	Man-months	Percent
Administration	81	14%
Block Diagrams, Mathematics, Aircraft Equations	109	20%
Storage	93	17%
Electronics, Input, Output, Conversion, Cockpit, Technical Supervision	275	49%
	558	100%

TABLE II

		Man-months	Percent
ADMINISTRATIVE		81	14%
Supervision	18		
Procurement, Stds., Stock	37		
Non-staff, shops, services	12		
ONR Liaison	7		
Contracts and Sub-contracts	7		
TECHNICAL SUPERVISION		32	6%
BLOCK DIAGRAMS		46	8%
Serial	19		
Parallel	27		
MATHEMATICS		43	8%
AIRCRAFT EQUATIONS		20	4%
Wind Tunnel Staff	8		
Whirlwind Staff	12		
COCKPIT		34	6%
INPUT, OUTPUT, CONVERSION		19	3%
Magnetic in-out	4		
Film in-out	2		
Binary - decimal conversion	5		
Binary analogue conversion	8		
STORAGE		93	17%
Research	39		
Construction	12		
Test	35		
Deflection	7		

TABLE II
(cont.)

		Man-months	Percent
ELECTRONIC SYSTEM DESIGN and TEST		41	7%
TEST EQUIPMENT		43	8%
Oscilloscope redesign	4		
Pulse generators	15		
Frequency dividers	2		
Miscellaneous	22		
FLIP-FLOP CIRCUITS		35	6%
Design	24		
Tolerance and stability	11		
PULSE TRANSFORMERS		23	4%
MISCELLANEOUS CIRCUITS and COMPONENTS		48	9%
Gate circuits and tubes	6		
Tube characteristics and life	3		
Switch circuits and crystals	13		
Line driving	7		
Coupling methods	6		
Delay elements	4		
Power supplies	5		
Miscellaneous circuits	4		
TOTAL WHIRLWIND STAFF EFFORT		558	100%

10.0 Organization and Facilities

The following sections outline the relation of the Project Whirlwind to other Massachusetts Institute of Technology activities, the project staff organization, and the available facilities with photographs.

10.1 M.I.T. Organization

Project Whirlwind is administered at the Massachusetts Institute of Technology by the Division of Industrial Cooperation. The D.I.C. has a number of laboratories each associated with some academic department of the Institute. The work of Project Whirlwind is carried out in the Servomechanisms Laboratory as a part of the Department of Electrical Engineering. The Laboratory can call on the Electrical Engineering Department for consultation and additional facilities when necessary, and has found this of invaluable help in carrying out the research work. Project Whirlwind has close relations with the Mathematics Department and has been greatly assisted by the Physics and Chemistry Departments. The details of these relationships are described elsewhere in this report. The Aeronautical Engineering Department worked for months on the preparation of the aircraft equations, the ranges of variables to be expected, and the very complete testing of a wind tunnel model to give actual aircraft data to work on.

The Servomechanisms Laboratory has its headquarters in Building 32 at M.I.T. but most of the Project Whirlwind engineering is in the Barta Building at 211 Massachusetts Avenue. Building 32 provides the project with a personnel department, accounting, and payroll facilities. The project drafting room is a branch of the Building 32 drafting room and personnel are exchanged as need arises.

10.2 Project Personnel and Organization

The personnel on Project Whirlwind consists at present of 45 staff members and a like number of technicians, administrative assistants, stock clerks, and secretaries. The total number in each category is given below:

Staff	45	
Technicians	19	
Secretaries	7	
Stock, purchasing, receiving, inspection	10	
Drafting	10	
Print department	2	
Building service including telephone operators, guards, receptionists, and maintenance	14	
Total non-staff	62	
Total staff and non-staff		107

In addition the project has access to the following personnel in Building 32:

Administrative Staff	
Purchasing and Accounting	6
Drafting	12
Machinists	9

The staff members of Project Whirlwind fall into two categories: some are on full time DIC appointments; others are full time Research Assistants or Research Associates having their appointments from the Electrical Engineering Department.

A complete list of the present staff members with their academic degrees will be found in Section 10.5. Fifteen members of the present technical staff had radar experience during the war which is directly useful in the project work. Six men not now with the staff have in the past made valuable contributions in video and pulse techniques.

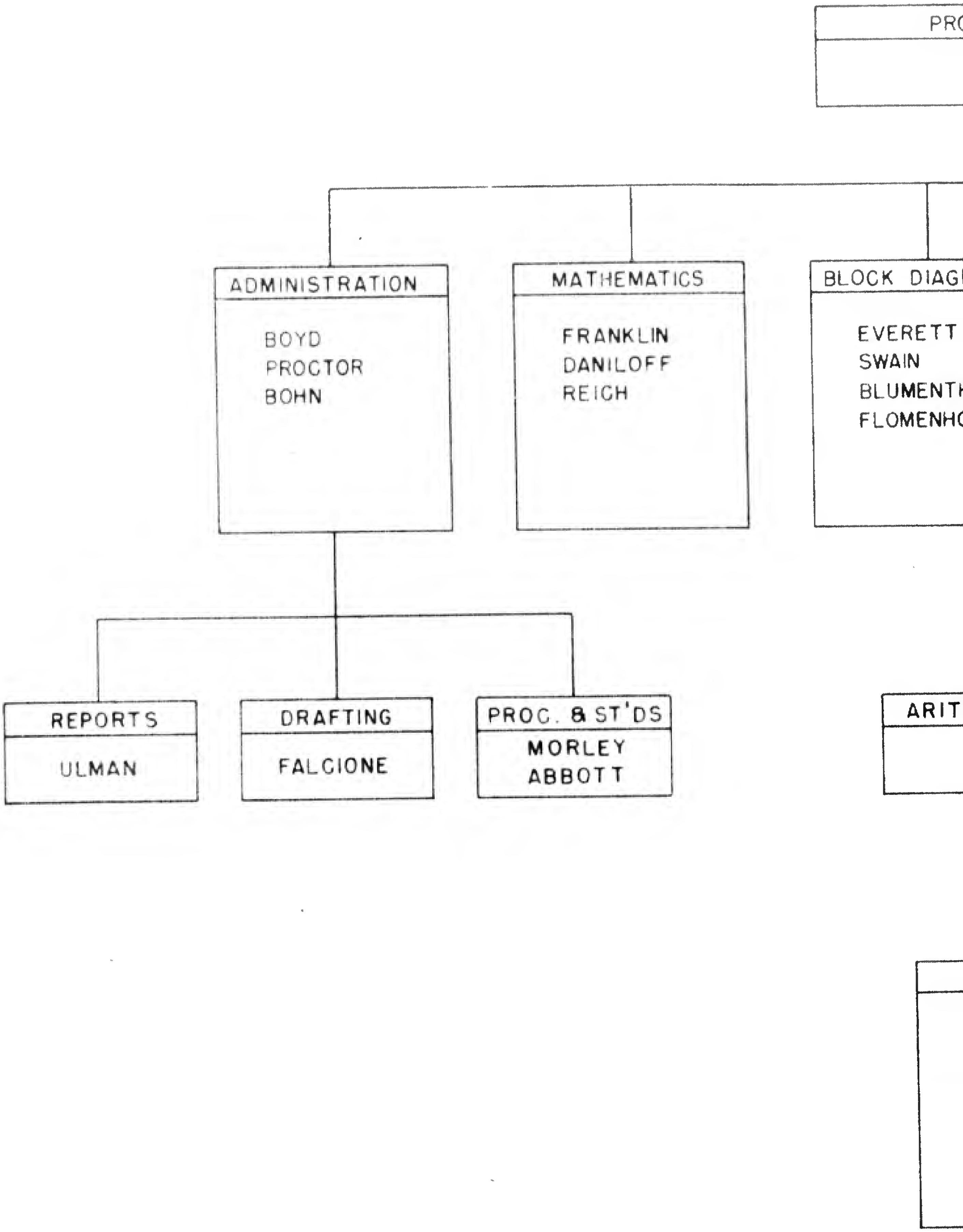
The general organization of the Project staff is shown in Drawing B-31201.

10.3 Facilities

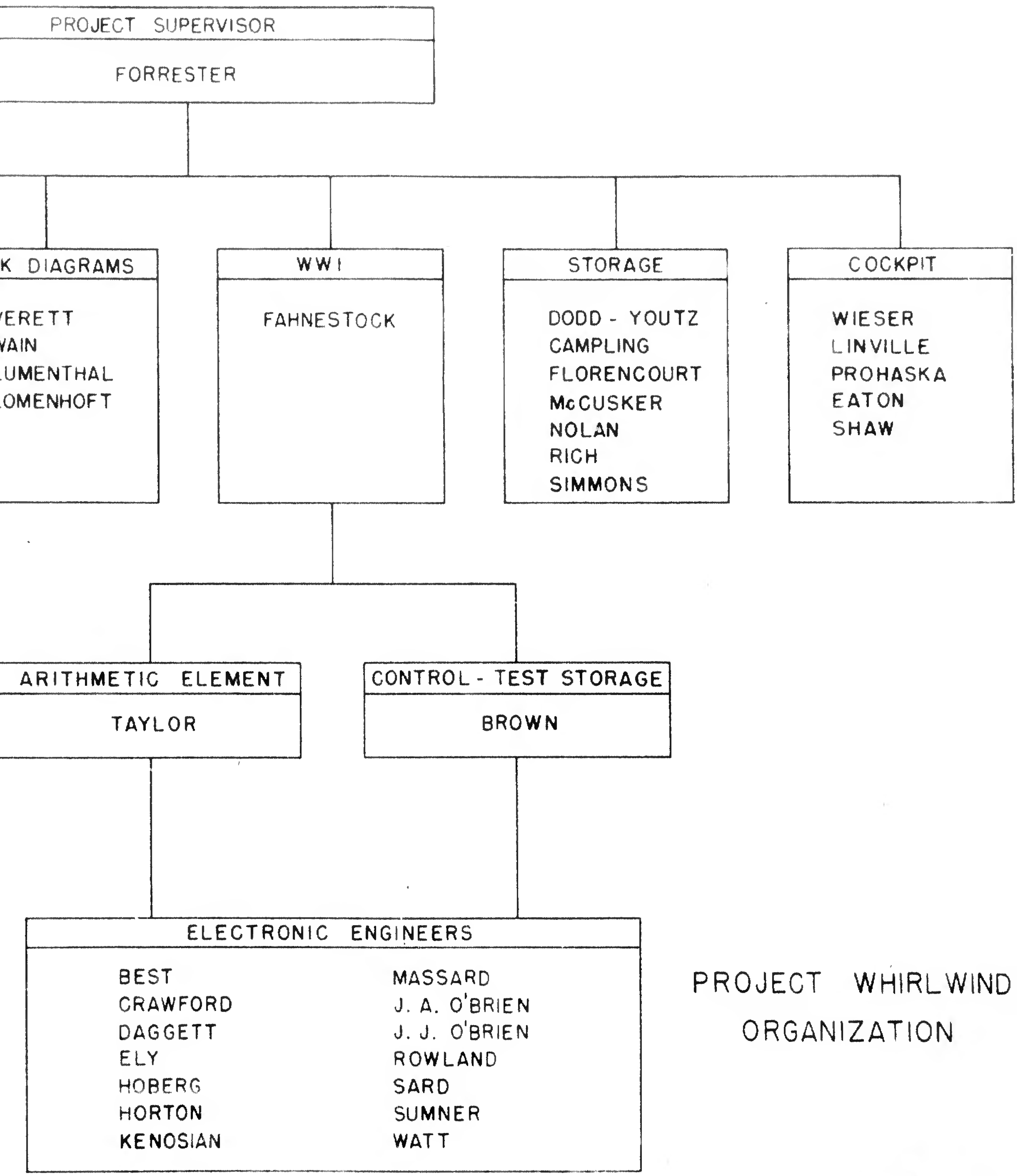
10.31 Available Space and Services

Project Whirlwind occupies the 28,000 gross square feet of the Barta Building at 211 Massachusetts Avenue, Cambridge, recently purchased by M.I.T. when the Navy was unable to provide the temporary housing for Project Whirlwind as originally planned. Drawings B-31174, B-31175, B-31176, are respectively the basement, first and second floor plans. A series of photographs is given in Section 10.4 showing much of the interior of the building.

Among other facilities the building includes in Room 016, DC power supplies at nine different voltages all of which are wired into the benches of the various laboratories, Rooms 114-134, 138, 222, 223.

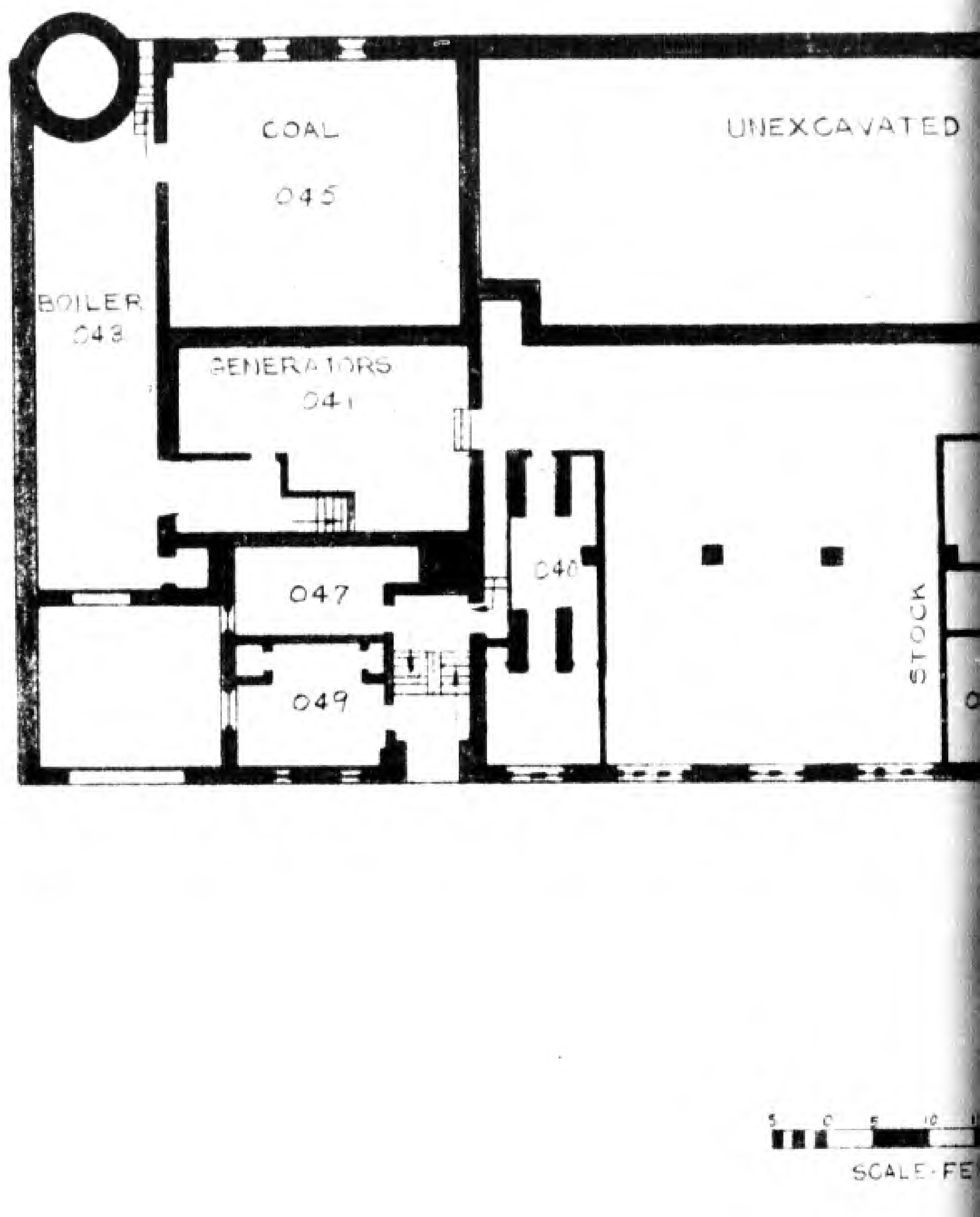

PRO
ADMINISTRATION
BOYD
PROCTOR
BOHN
MATHEMATICS
FRANKLIN
DANILOFF
REICH
BLOCK DIAG
EVERETT
SWAIN
BLUMENTH
FLOMENHO
REPORTS
ULMAN
DRAFTING
FALCIONE
PROC. & ST'DS
MORLEY
ABBOTT
ARIT

B-31201

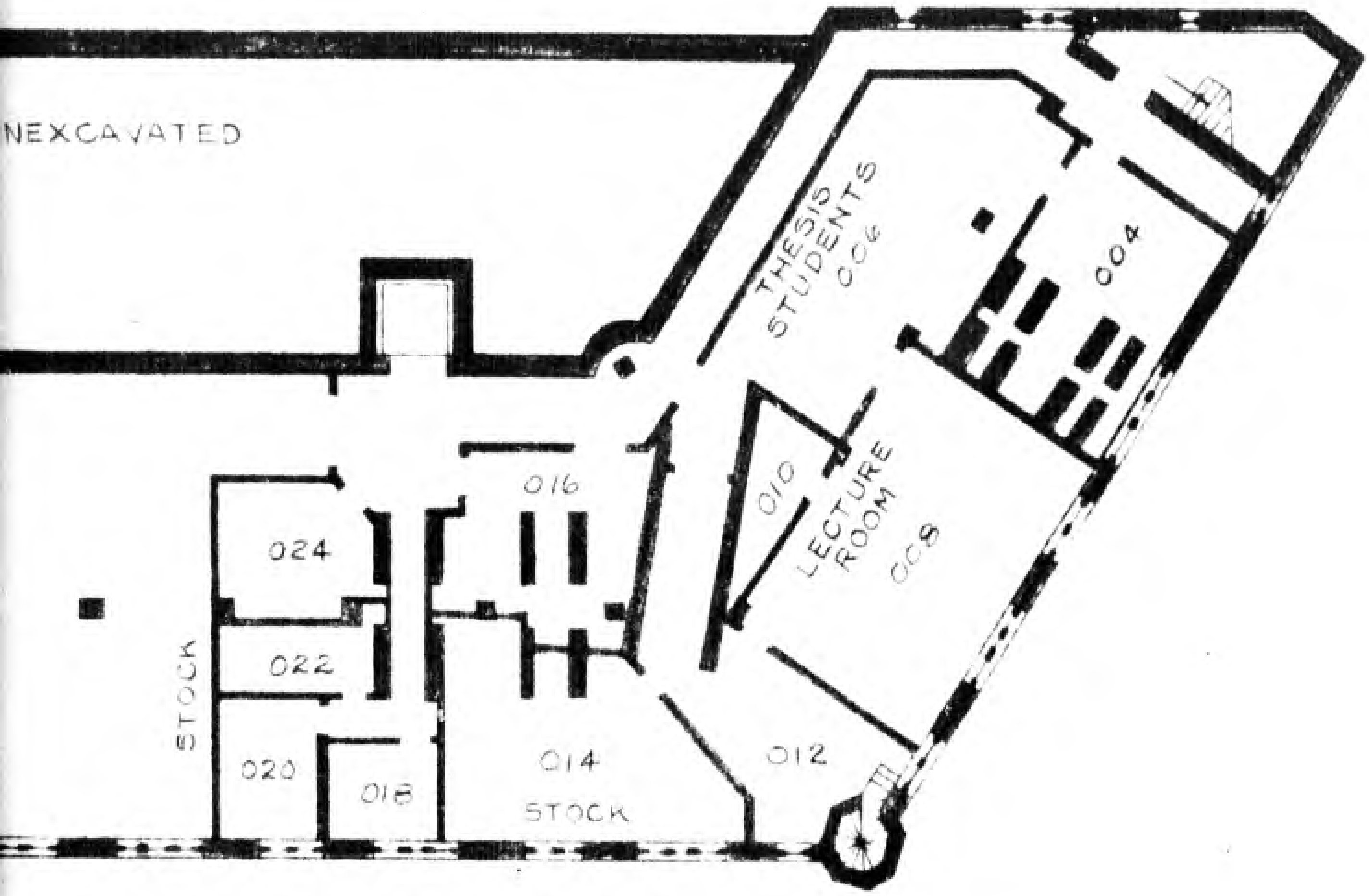


PROJECT WHIRLWIND
ORGANIZATION

B-312



"ALBANENE" NO. 106L K&E CO. N.Y.



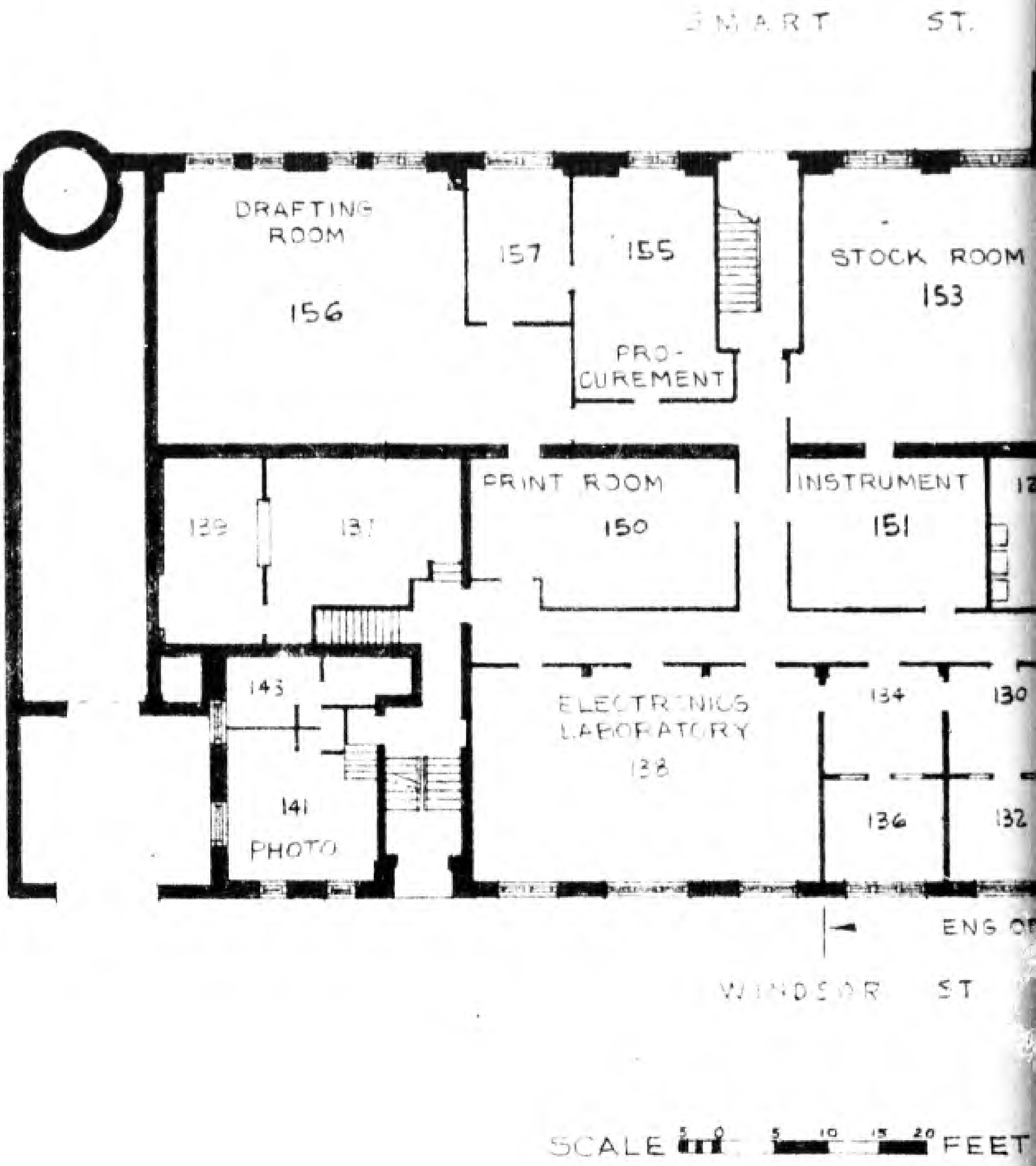
5 0 5 10 15 20 25

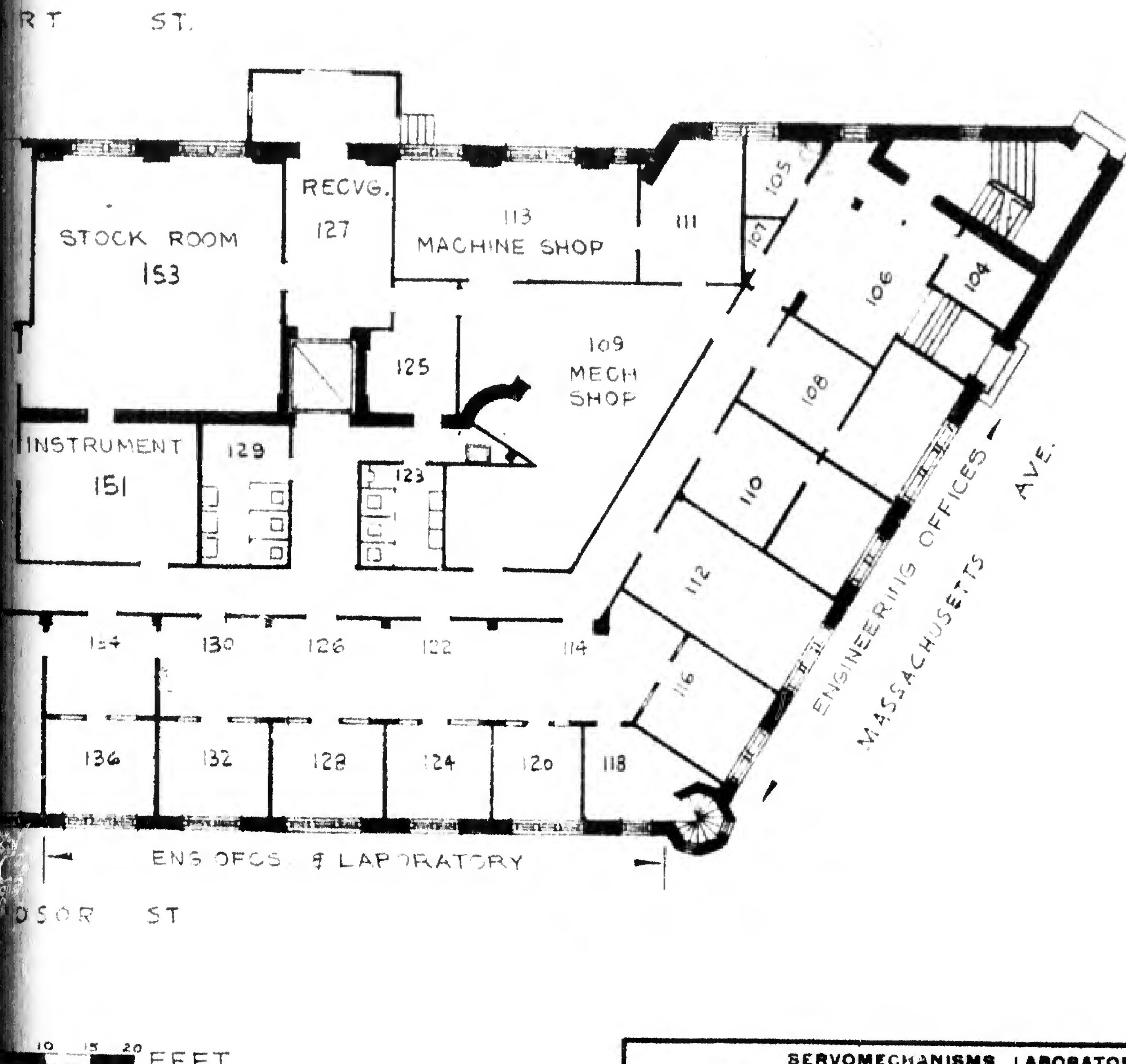
SCALE-FEET

SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

BASEMENT PLAN
(BARTA BUILDING)

SCALE.	DR. F. Z. [illegible]	B-31174
ENG.	CK.	APP.

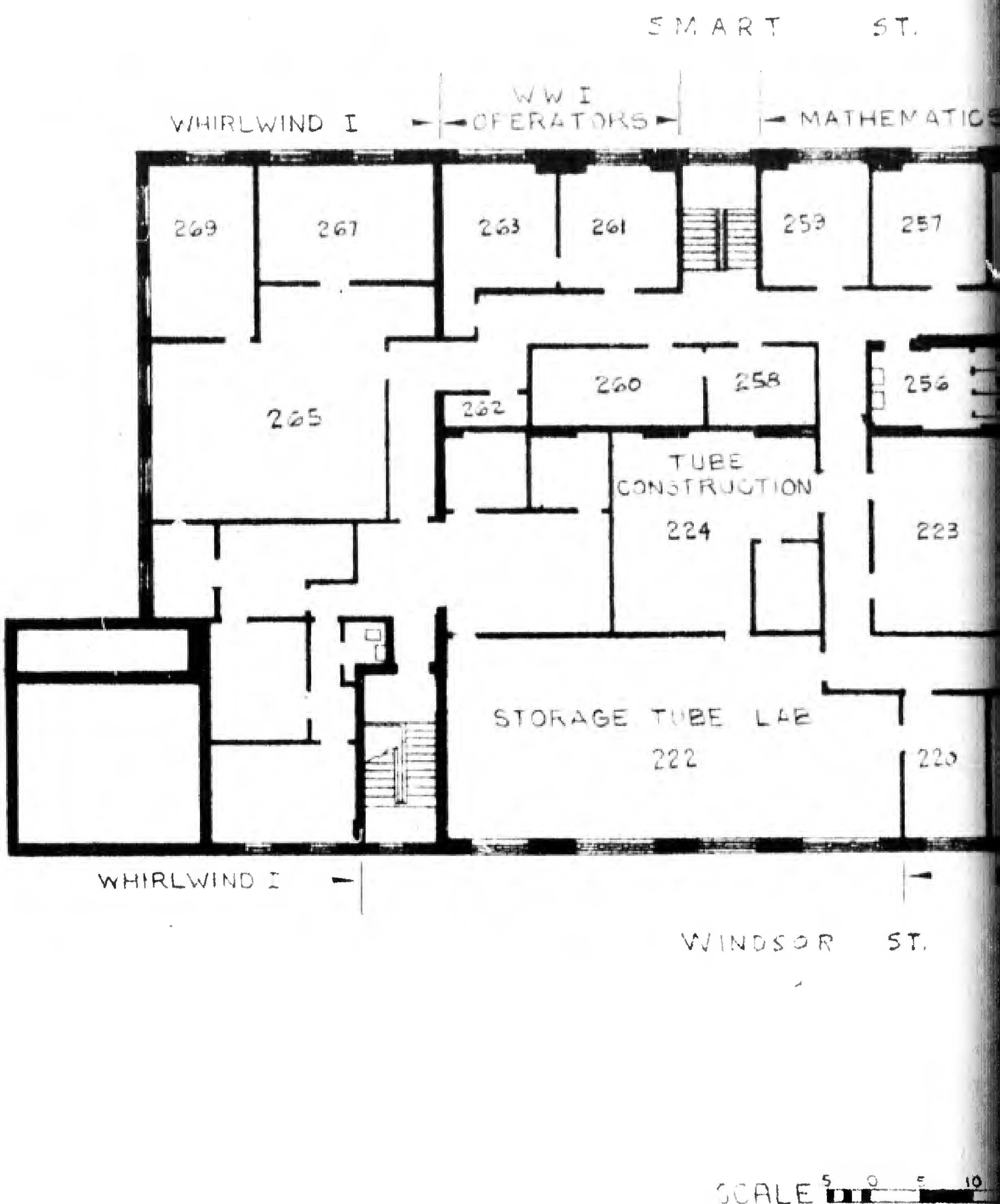

SMART ST.
DRAFTING ROOM
156
157
155
PRO-
CUREMENT
STOCK ROOM
153
PRINT ROOM
150
INSTRUMENT
151
139
137
143
141
PHOTO
LABORATORY
138
134
130
136
132
WINDSOR ST
SCALE
FEET

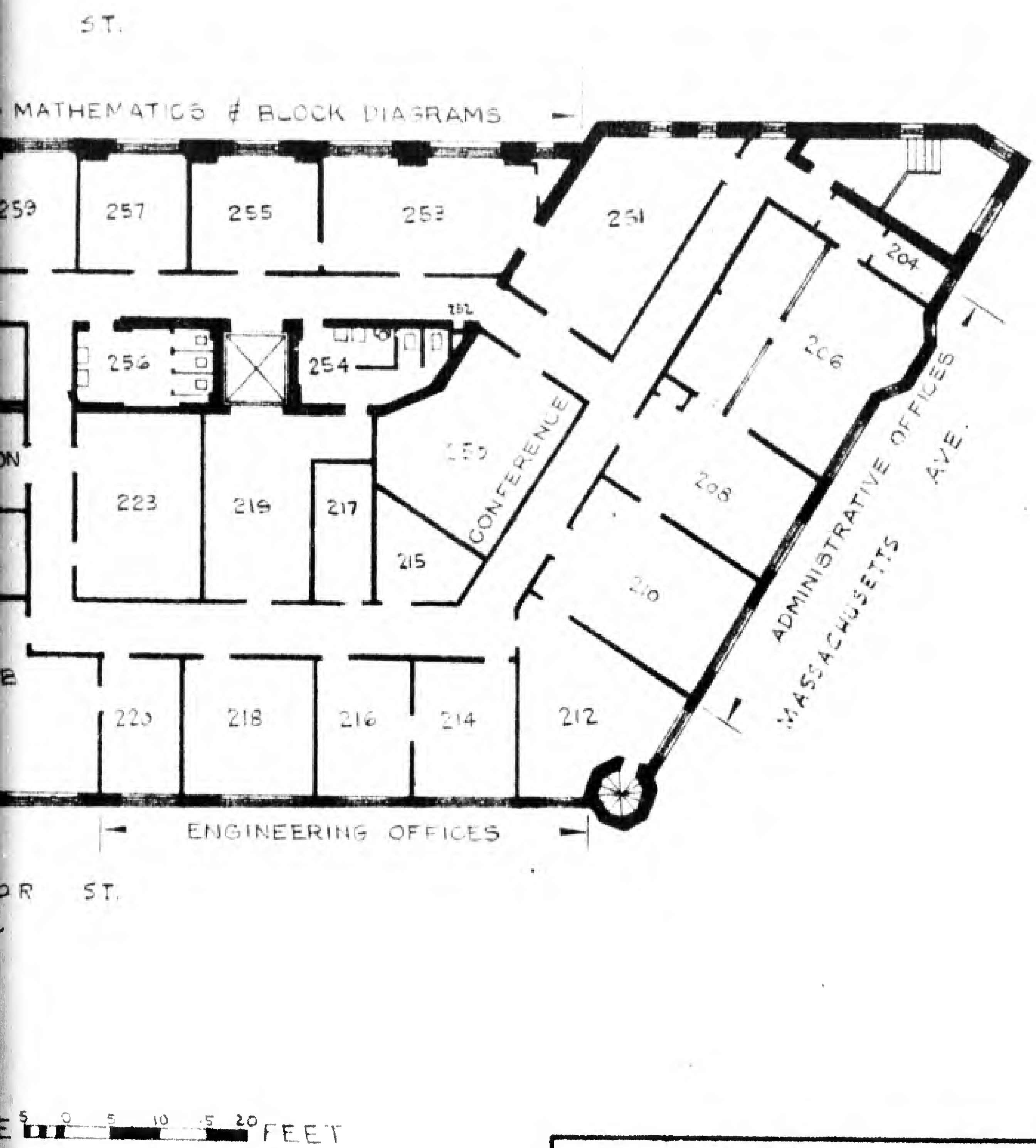


SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

FIRST FLOOR - BARTA BLDG

SCALE:	DR. 5-3-47	B-31175
ENG	CK.	APP.


SMART ST.
WHIRLWIND I
WWI OPERATORS
MATHEMATICS
269
267
263
261
259
257
265
262
260
258
256
TUBE CONSTRUCTION
224
223
STORAGE TUBE LAB
222
220
WHIRLWIND I
WINDSOR ST.
SCALE
5
0
5
10



SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

SECOND FLOOR - BARTA BLDG.

SCALE:	DR. 5-9-47		B-31176
ENG	CK.	APP.	

Section 10.31

Room 008 is a lecture room 18 x 24 feet, capable of seating 60 people and used for staff meetings and instruction and training courses. Room 113 is a small machine shop for the use of technicians and qualified staff members. The machine shop and mechanical shop are staffed with five technicians. A list of the machine tools available in the building will be found at the end of the text in this volume.

Building 32, the headquarters of the Servomechanisms Laboratory, provides a complete machine shop for handling work beyond the capacity of the shop in the Barta Building. Building 32 also maintains a procurement department which is capable of providing additional machine work including small production quantities through contracts with job shops throughout the Boston area.

The Drafting Room, 156, in the Barta Building provides facilities for twelve draftsmen and a supervisor. The Drafting File and Print Room, 150, includes an Ozalid Streamliner which will make the latest types of reproductions including photographs and chart film, and an automatic electric ditto machine with a capacity of 1,000 sheets per hour. The drafting, print, and ditto facilities of Building 32 are also available to Project Whirlwind. Rooms 141 and 143 provide photographic facilities. The photographic equipment is listed at the end of the text. The stock and instrument supplies are kept in Rooms 153 and 151.

The Whirlwind I computer will be located on the second floor with the input and output equipment in Rooms 261 and 263. The remainder of the computer will occupy a single room with an area of 1,600 square feet consisting of the present rooms, 267, 269, 265, and the rooms adjacent to 265 on the second floor.

Room 217 contains a small library of reports, texts, and reference books useful in the work of the project.

10.32 Electronic Engineering Facilities

Room 138 is an electronic technicians laboratory. The eight technicians who occupy this room are engaged in building experimental equipment for the engineers, special test equipment designed by this project, and prototype construction for the Whirlwind I system. All benches are wired for 110 volt A.C., 6.3 volt A.C., and 9 D.C. voltages.

The Rooms 134 through 136 are used by the electronic engineers on the project for their office space and laboratory work. Two engineers are assigned to each pair of rooms, the room nearer the outside wall being used for office space and the room nearer the corridor being used for laboratory area. For example, two engineers occupy the pair of Rooms 134 and 136. Room 136 is used as an office while 134 contains the benches and experimental work being performed by these engineers. Photographs of the laboratory work carried on in these rooms will be found at the end of this volume.

10.33 Storage Tube Development Facilities

The storage tube development facilities are contained in Rooms 222 and 224. The storage tube laboratory, Room 222, includes benches for the five technicians and work space for the seven engineers engaged on the storage tube program. This laboratory includes facilities for the construction of special test equipment as well as storage tube elements, equipment for the preparation of dielectric surfaces by anodizing, test equipment for the study of secondary emission characteristics, and complete equipment for testing experimental and final storage tubes. The tube construction laboratory, Room 224, includes two complete vacuum systems, a 45 kilowatt input RF bomber, glass blowing benches, a spot welder, and a small stockroom. There is also a glass lathe in the storage tube laboratory. The laboratory is equipped not only for the construction of experimental tubes but also for the quantity of storage tubes needed for Whirlwind I. Photographs of these facilities are given at the end of this volume.

10.4 Photographs

Figure	Photograph No.	Title
1	FB-301	Barta Building
2	FB-294	D.C. Rectifier System
3	FB-290	Lecture Room
4	FB-285	Machine Shop in Room 113
5	FB-300	Building 32
6	FB-299	Building 32 Machine Shop
7	FB-289	Drafting Room

Section 10.4

Figure	Photograph No.	Title
8	FB-288	Blueprint Room
9	FB-286	Stock Room
10	FB-287	Instrument Room
11	FB-274	Electronic Technicians Laboratory
12	FB-278	Test Equipment Development Engineering Laboratory, Room 126
13	FB-275	Video Amplifier Design Engineering Laboratory, Room 136
14	FB-281	Pulse Transformer Development Engineering Laboratory, Room 122
15	FB-284	Resistor Check Engineering Laboratory, Room 122
16	FB-283	Vacuum Tube Tests Engineering Laboratory, Room 126
17	FB-276	Blackout Effect Investigations Engineering Laboratory, Room 136
18	FB-282	Flip-flop Circuit Development Engineering Laboratory, Room 130
19	FB-277	A C Coupled Flip-flop Development, Engineering Laboratory, Room 130
20	FB-280	System Testing, Engineering Laboratory, Room 120
21	FB-279	Crystal Matrix Switch Testing Engineering Laboratory, Room 118

Section 10.4

Photo No. FB301

Title Barta Building

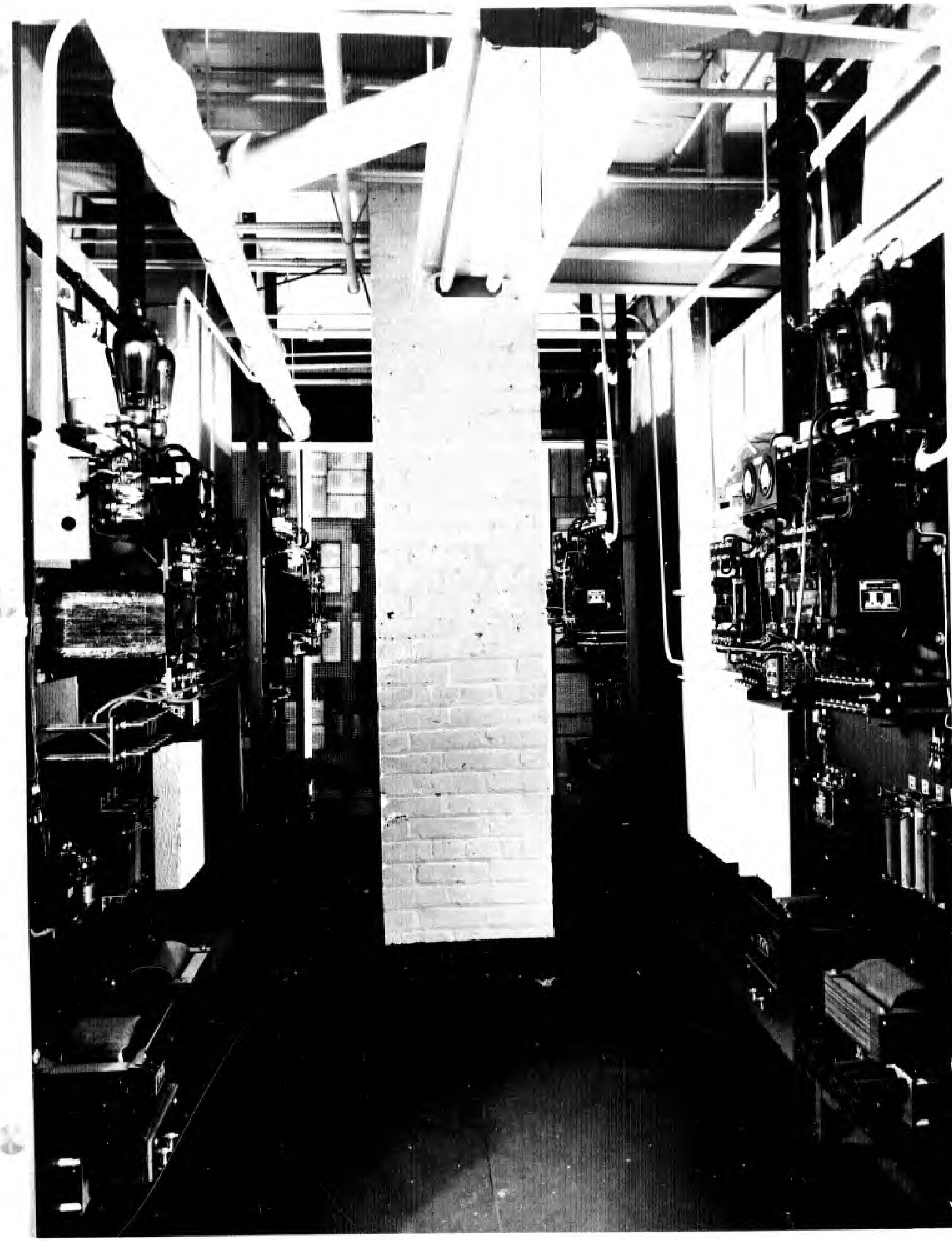
The Barta Building at 211 Massachusetts Avenue, Cambridge, was purchased by M. I. T. for Project Whirlwind. The photograph shows the Massachusetts Avenue and Windsor Street sides of the building. The main entrance is at the right of the photograph. The shipping entrance is off the alley that begins just to the right of the building. The main buildings of M. I. T. are about two blocks to the right on Massachusetts Avenue.


FB-301

Photo No. FB294

Title D. C. Rectifier System

This view shows part of the D.C. Rectifier Power Supplies in Room 016 in the Barta Building. Nine D.C. voltages are generated and are wired to all the Laboratories in the building.



FB—294

Photo No. FB290

Title Lecture Room

Room 008 is a lecture room 18 x 24 feet capable of seating 60 people. It is used for staff meetirgs. A complete course will shortly commence for the staff and other M. I. T. personnel. The room will be available in the future for the instruction and training of academic classes in computer techniques.

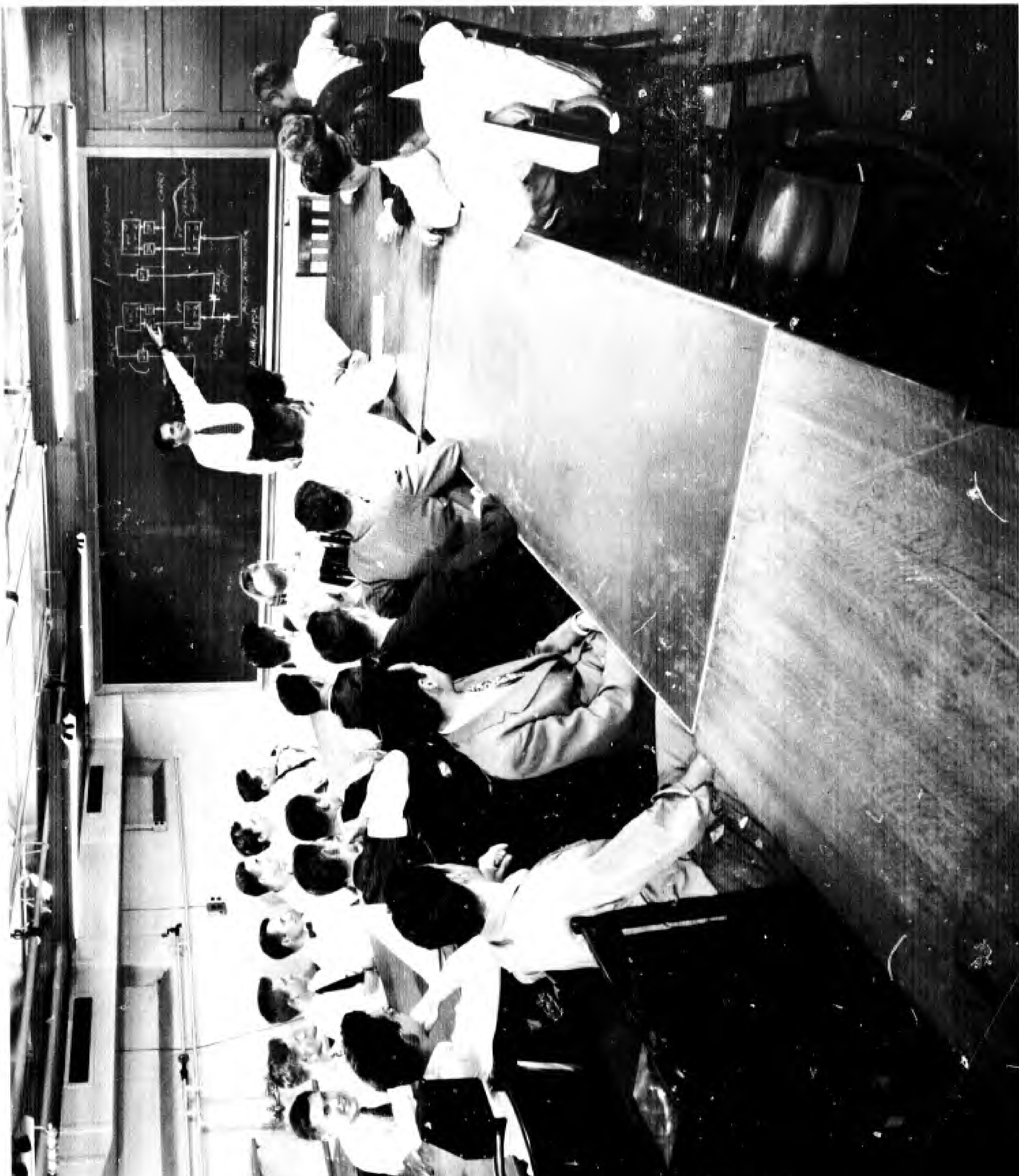


Photo No. FB285

Title Machine Shop in Room 113

This machine shop is for the use of technicians and qualified staff members. Attached to it is a mechanical shop staffed by five technicians. Shown in the photograph are a fifty-two inch 18 gauge shear, two South Bend lathes, a Bridgeport vertical milling machine, a Burke milling machine, and a drill press. Not shown but also included in the shop are a punch press, a brake, a bandsaw, a jigsaw, a sanding machine, and a tool grinder.


FB-285

Photo No. FB300

Title Building 32

Building 32 is the parent building of the Servomechanisms Laboratory of which Project Whirlwind is a part. In Building 32 are personnel, purchasing, accounting, and payroll facilities for the laboratory. The Servomechanisms Laboratory carries on a number of other government and industrial research projects in Building 32.


BLDG 32
FB-300

Photo No. FB299

Title Building 32 Machine Shop

Building 32 maintains for the Servomechanisms Laboratory a complete machine shop including inspection and assembly departments. This shop is staffed with competent machinists. Also available in Building 32 is a procurement department which maintains contacts throughout the Boston area with job shops capable of performing machine work whose specialty or quantity makes it beyond the reach of the Servomechanisms Laboratory facilities.


FB-299

Photo No. FB289

Title Drafting Room

The drafting room, Room 156 in the Barta Building, provides facilities for twelve draftsmen and a supervisor. Drafting personnel includes machine designers and circuit layout men as well as detailers.


FB289

Section 10.4

Photo No. FB288

Title Blueprint Room

At the far end of the room is a modern Ozalid Streamliner print machine capable of making all the latest types of reporductions. At the left is an automatic electric Ditto machine with a capacity of one thousand sheets per hour. The table in the center holds printing material as well as providing work space. On the right and extending out of sight toward the camera are the drawing files.


FB 288

Section 10.4

Photo No. FB286

Title Stock Room

Shown in this photograph is one of the rows of stock shelves in Room 153. A large selection of electronic components of all types is kept. One activity is the establishment of standards for these components as well as specifications and methods of test.


B
FB-28

Photo No. FB287

Title Instrument Room

The shelves at the left hold a part of the electronic test equipment available to the project including a number of power supplies. The bulk of the test equipment owned by the project is in use throughout the building. Assigned stock is also kept in this room beyond the photograph on the right.

A
FB-287

Photo No. FB274

Title Electronic Technicians Laboratory

The electronic technicians occupy Room 138 on the first floor of the building. At present eight technicians are engaged in building experimental equipment for the engineers, special test equipment designed by this project, and prototype construction for the Whirlwind I system. All benches are wired for 110 volts A.C., 6.3 volts A.C., and 9 D.C. voltages.

Photo No. FB278

Title Test Equipment Development

Engineering Laboratory, Room 126

Test equipment suited to the high speeds of the computer is one of the most important basic subjects of the work. This photograph shows several different pieces of equipment designed, built, or under development in this laboratory. In the rack are three Project developments in common use throughout the laboratory. At the top is a Variable Frequency Clock-pulse Generator (Vol. 19, E-48). In the center, is a Restorer-pulse Generator (Vol. 19, E-52), and at the bottom is a Decade Counter used as frequency divider for synchronizing the TS-239/UP oscilloscope at the right. On the shelf to the rear is a different type of frequency divider. A Restorer-pulse Distributor is being developed here.

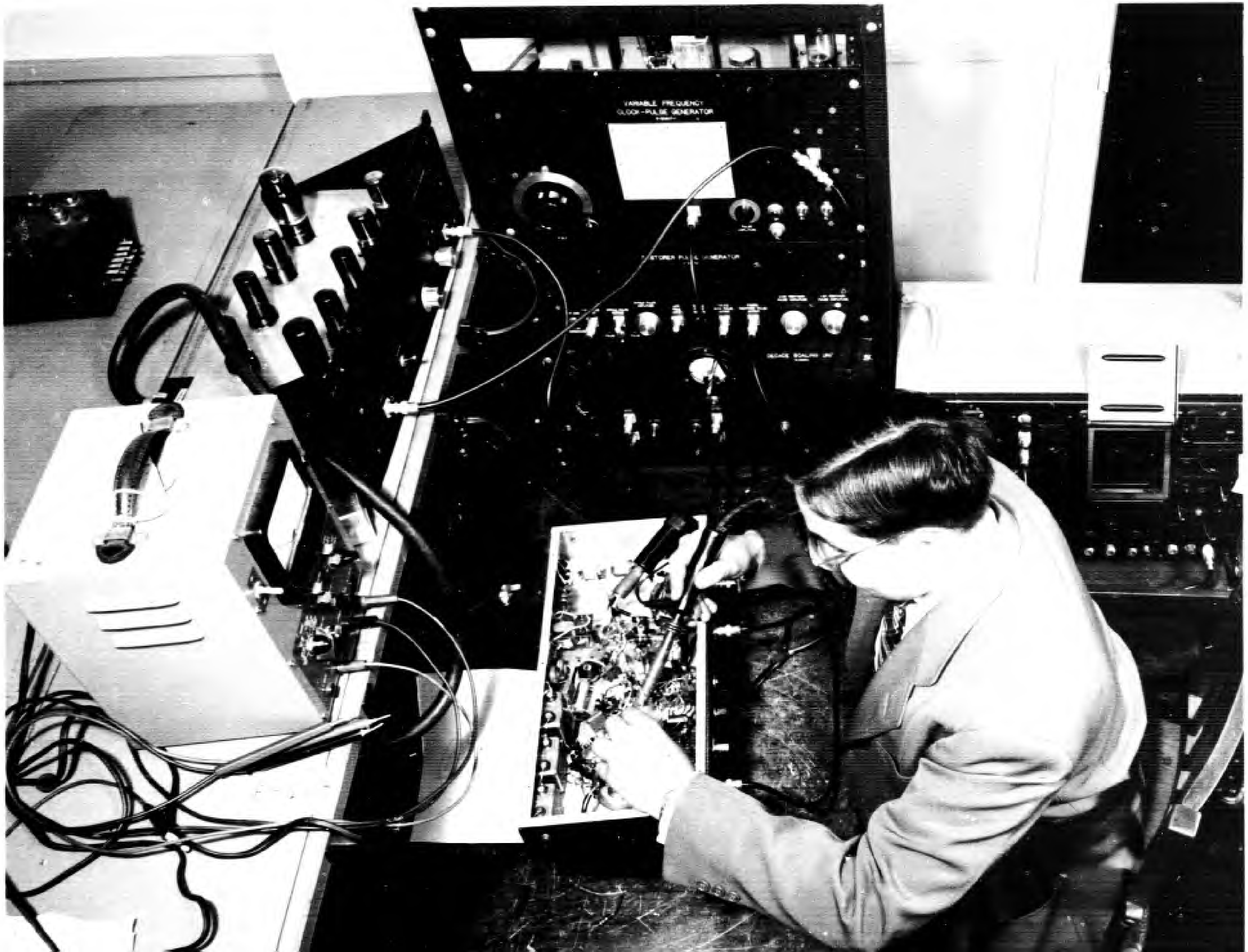

VARIABLE FREQUENCY
CLOCK-PULSE GENERATOR

Photo No.	FB275
Title	Video Amplifier Design, Engineering Laboratory, Room 136

Additional test equipment is shown in this photograph. The engineer is working on the lay-out of a wide-band video amplifier to be installed in the Model 5 Synchroscope at the right.

Photo No. FB281

Title Pulse Transformer Development,
Engineering Laboratory, Room 122

Component development receives a great deal of attention. This photograph shows the test bench of two engineers who are continuing the work on pulse transformers (Vol. 18, R-122). Included in this set-up is a gate and delayed trigger generator (Vol. 19, E-38), which has wide application. This device is shown just between the synchroscope and the variable frequency clock-pulse generator. The nine standard D. C. voltages in the building are wired to this bench. The power supplies on the top shelf are used for special purposes.

- - -

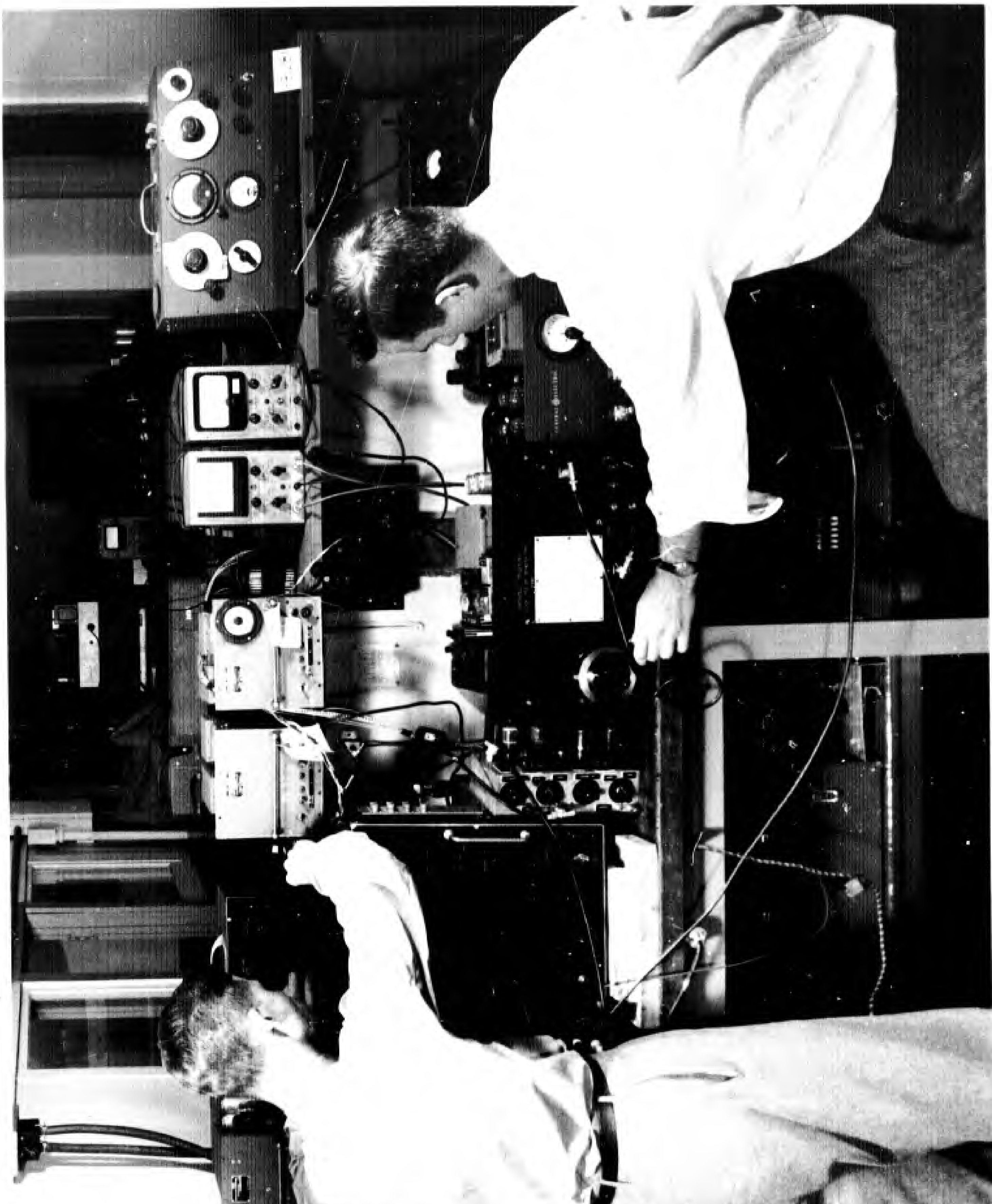


Photo No. FB284

Title Resistor Check,

Engineering Laboratory, Room 122

To insure reliability of the computer, commercial components must be selected with great care. This photograph shows a test on surface temperature of resistors to check manufacturers dissipation ratings.


FB 284

Photo No. FB283

Title Vacuum Tube Tests,

Engineering Laboratory, Room 126

Study of vacuum tubes and their characteristics requires a considerable amount of project effort. This photograph shows work on an SR-1030 in a typical gating circuit. No suitable tubes were available for this purpose and the SR-1030 was developed for this project by Sylvania (Vol. 16, E-73). Part of the set-up is a gas tube pulse generator developed and built in the laboratory.

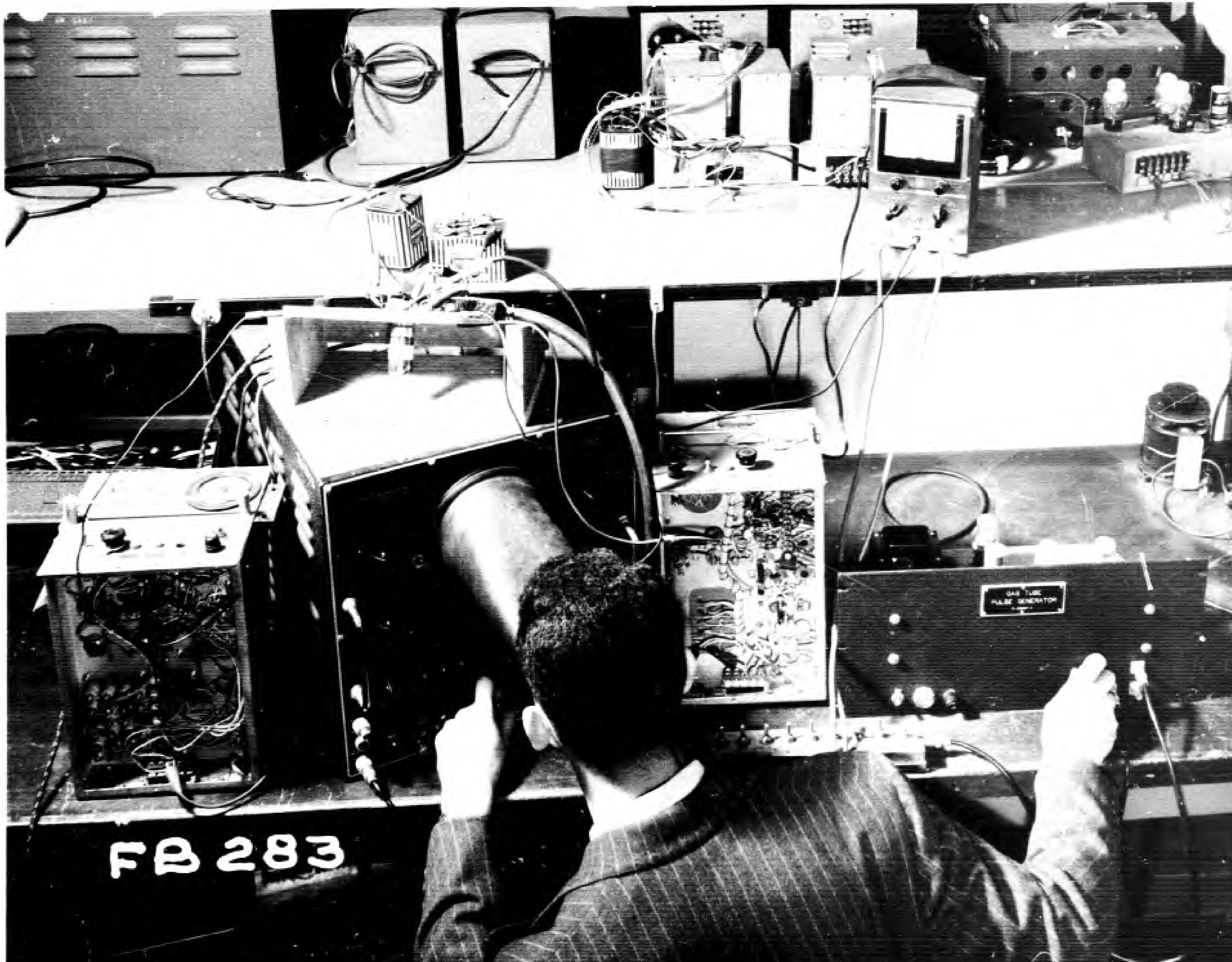

GAS TUBE
PULSE GENERATOR
FB 283

Photo No. FB276

Title Black-out Effect Investigations, Engineering Laboratory, Room 136

Pulsed vacuum tubes operated at a high repetition frequency may exhibit an intolerable black-out effect. This photograph shows a set-up for measuring this effect. The set-up includes a gas tube pulse generator, two gate and delayed trigger generators, and a new type of commercial oscilloscope.


FB-276

Photo No. FB282

Title Flip-flop Circuit Development,

Engineering Laboratory, Room 130

Circuits are the building blocks from which systems are made. In a rack at the right of this photograph are several possible flip-flop circuits one of which is being tested. Wave forms are being traced directly on the scope to give a permanent record of tests. Above the scope is a commercial version of a decade scaling unit. Oscilloscope cameras are available on the project but are less convenient for uses such as these.

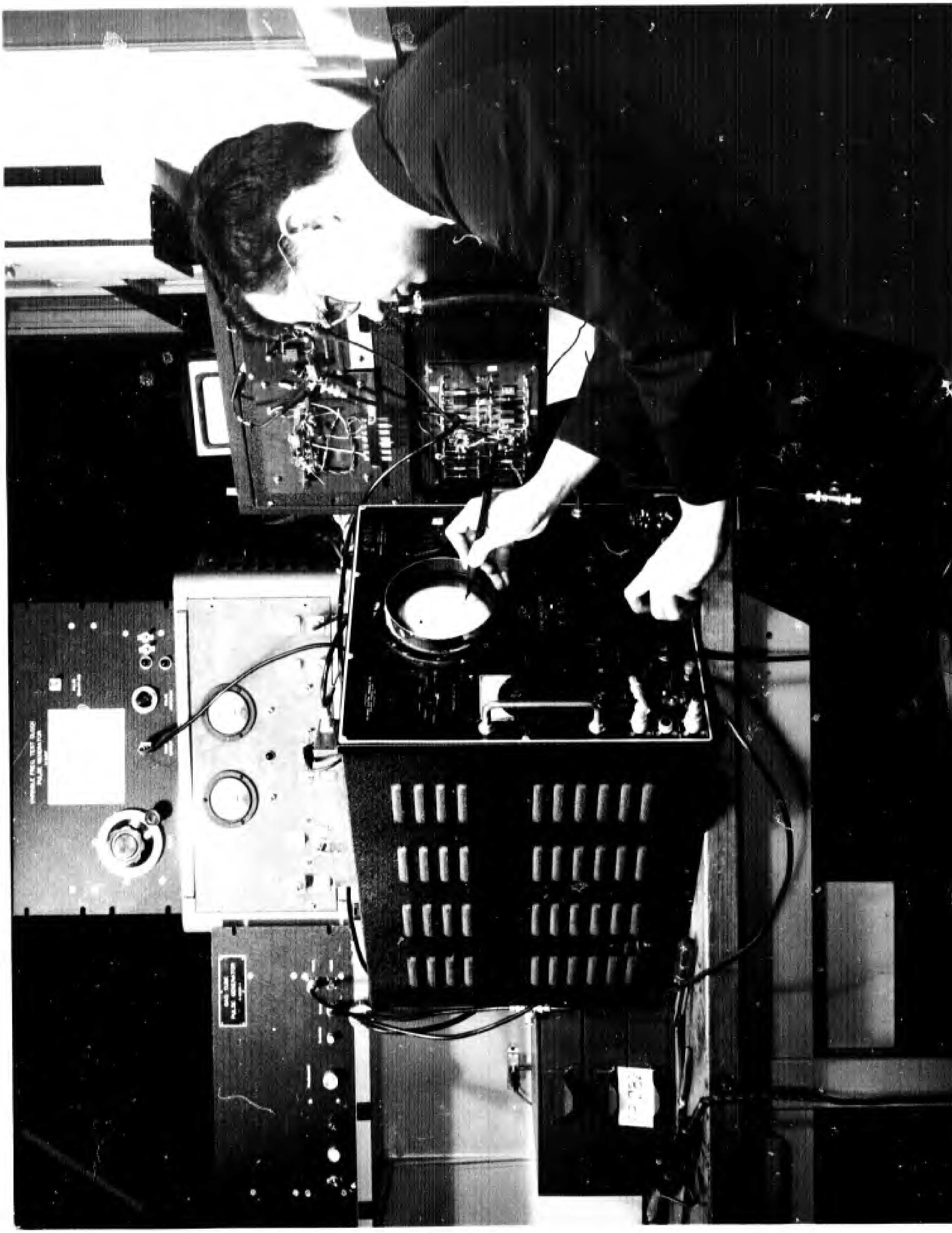


Photo No. FB277

Title A.C. Coupled Flip-flop Development

Engineering Laboratory, Room 130

One of the important features of the Whirlwind Computer is the use of A.C. coupling which greatly reduces the tolerances required on circuit components and on power supply voltages. At present, the flip-flops within the computer are still D. C. coupled but here work is progressing on the design of an A. C. coupled flip-flop.

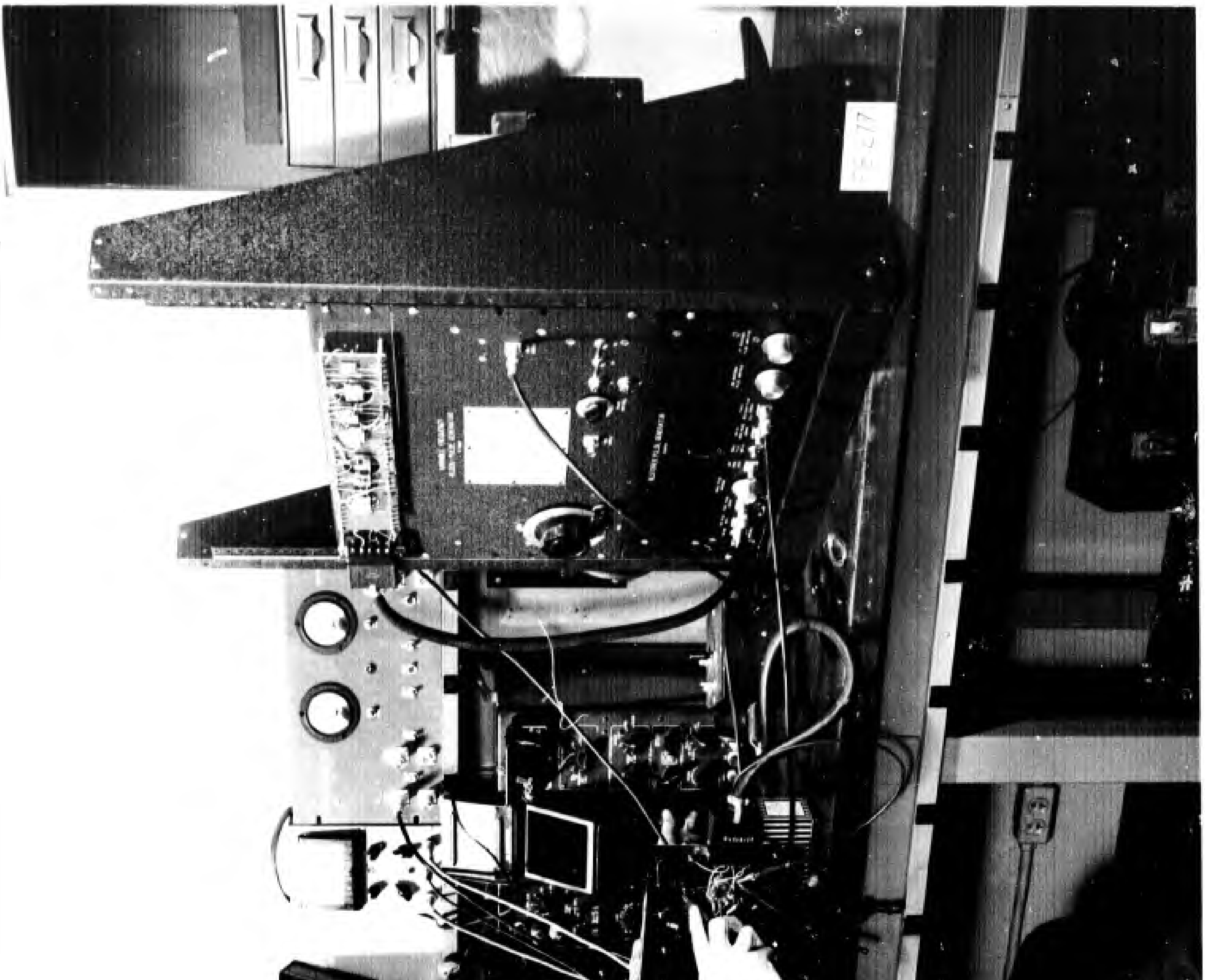


Photo No. FB280

Title System Testing,
Engineering Laboratory, Room 120

In the course of system design more and more circuits must be combined. In order to prove out the systems designed for the check register, program register, and program counter, (Vol. 19, E-55, M-105, E-63), a synthetic panel was built combining the most difficult parts of each. This panel is shown in the rack at the right-hand side. At the center of the bench turned so that only its bottom is showing is the first model of a decimal to binary converter which is needed for the computer input (Vol. 12).

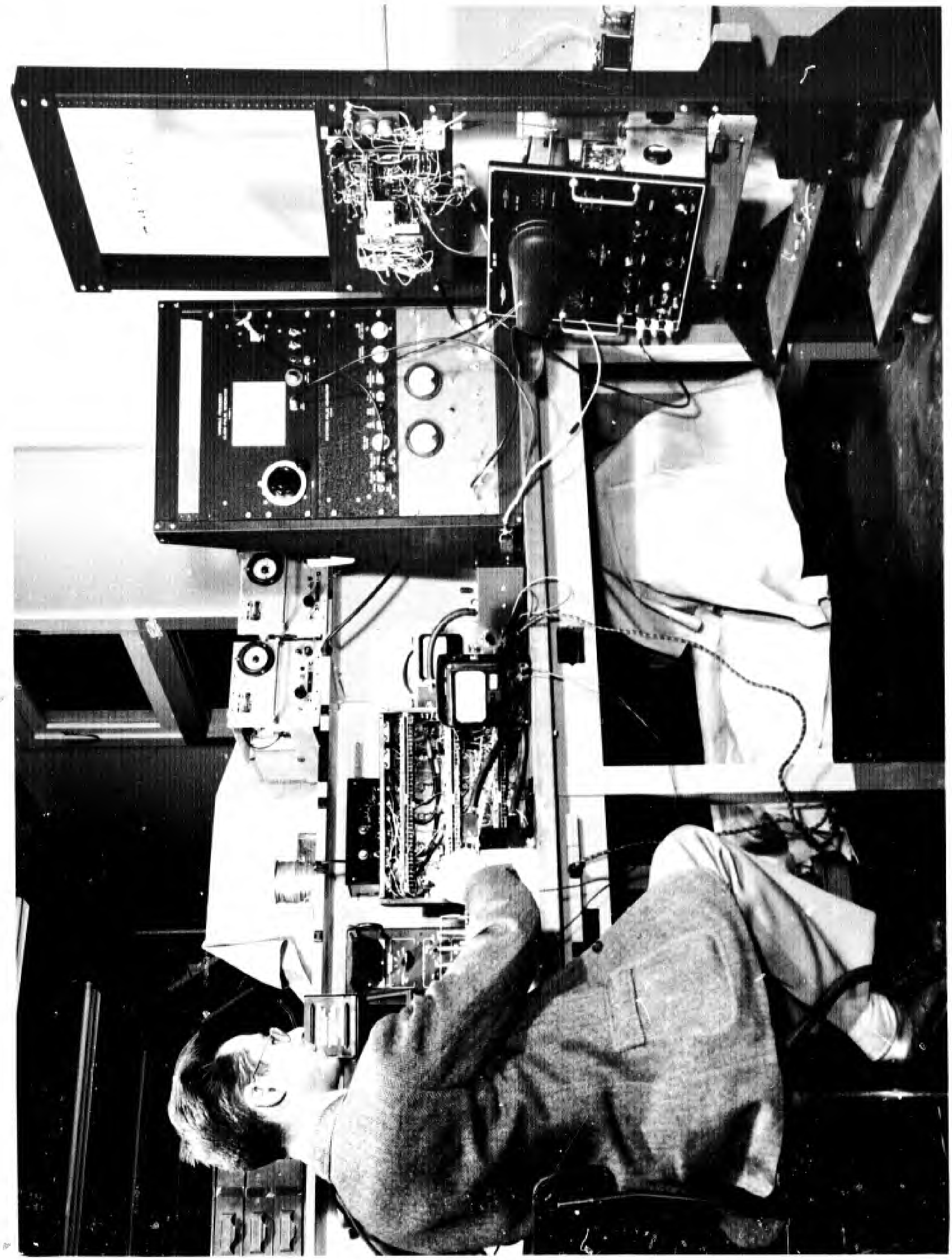


Photo No. FB279

Crystal Matrix Switch Testing

Engineering Laboratory,

Room 118

The crystal matrix switch is an important component in the Whirlwind Computer. A high speed version of a thirty-two position crystal matrix switch (Vol. 17), is shown for switching in 0.2 microsecond.

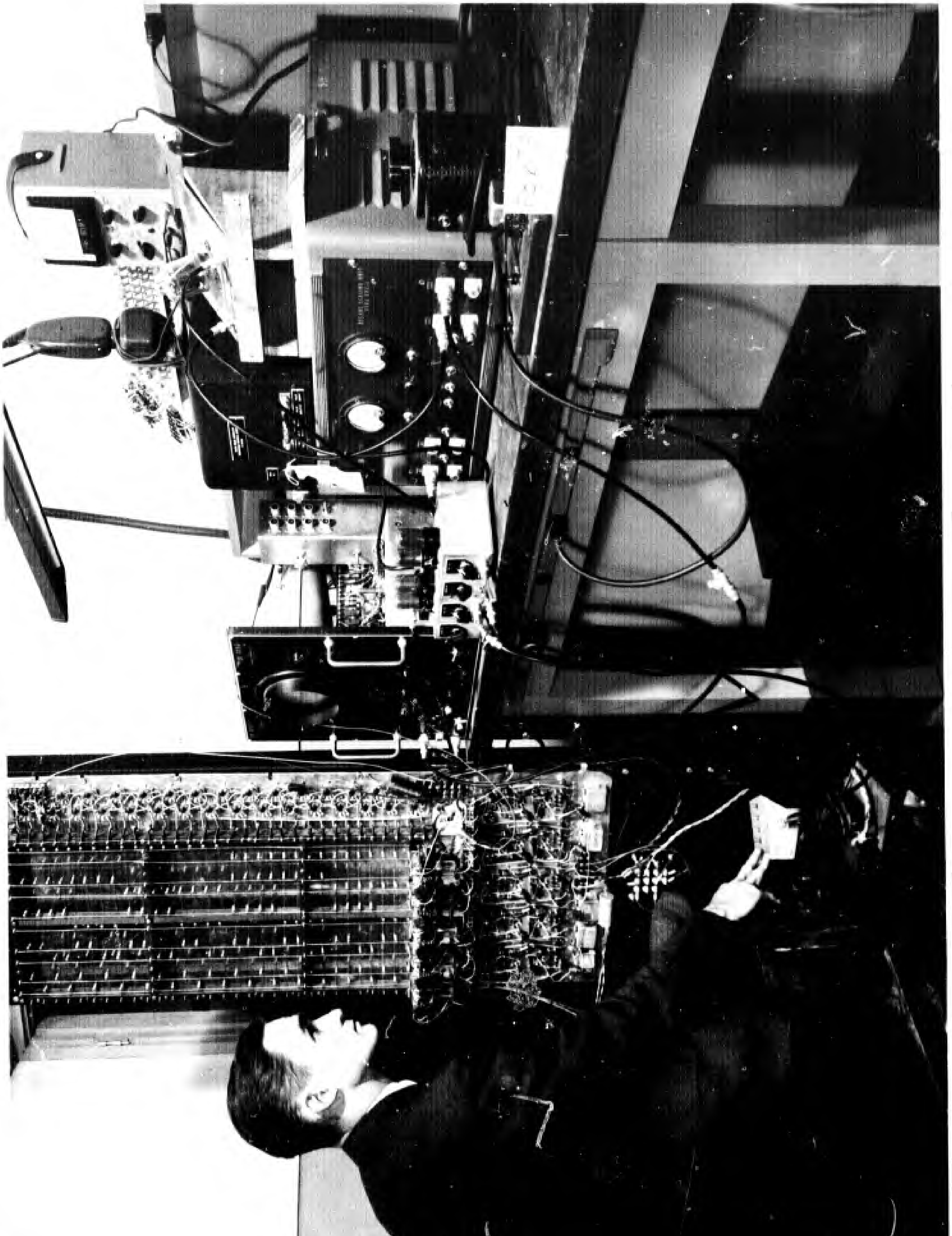


Photo No. FB238

Title Storage Tube Laboratory

Most tube testing is done in this room. In addition there are a tube construction room and several offices assigned to the storage tube group. The benches in the foreground are used by technicians for the construction of special equipment and assembling of storage tube elements. Work in anodizing and in secondary emission characteristics is carried on at the next benches. In the far end of the room completed experimental storage tubes are tested. At the right, beyond the edge of the photograph, is the glass lathe shown in a later figure.


DANGER
DANGER
DANGER
DANGER
FB298

Photo No. FB112

Title Anodizing Apparatus

The anodizing bath and electrode structure is shown in the center of the photograph, while the electrical control apparatus is on the left. Laboratory power is available for this purpose. Anodizing is used to produce dielectric surfaces for storage tube assemblies.

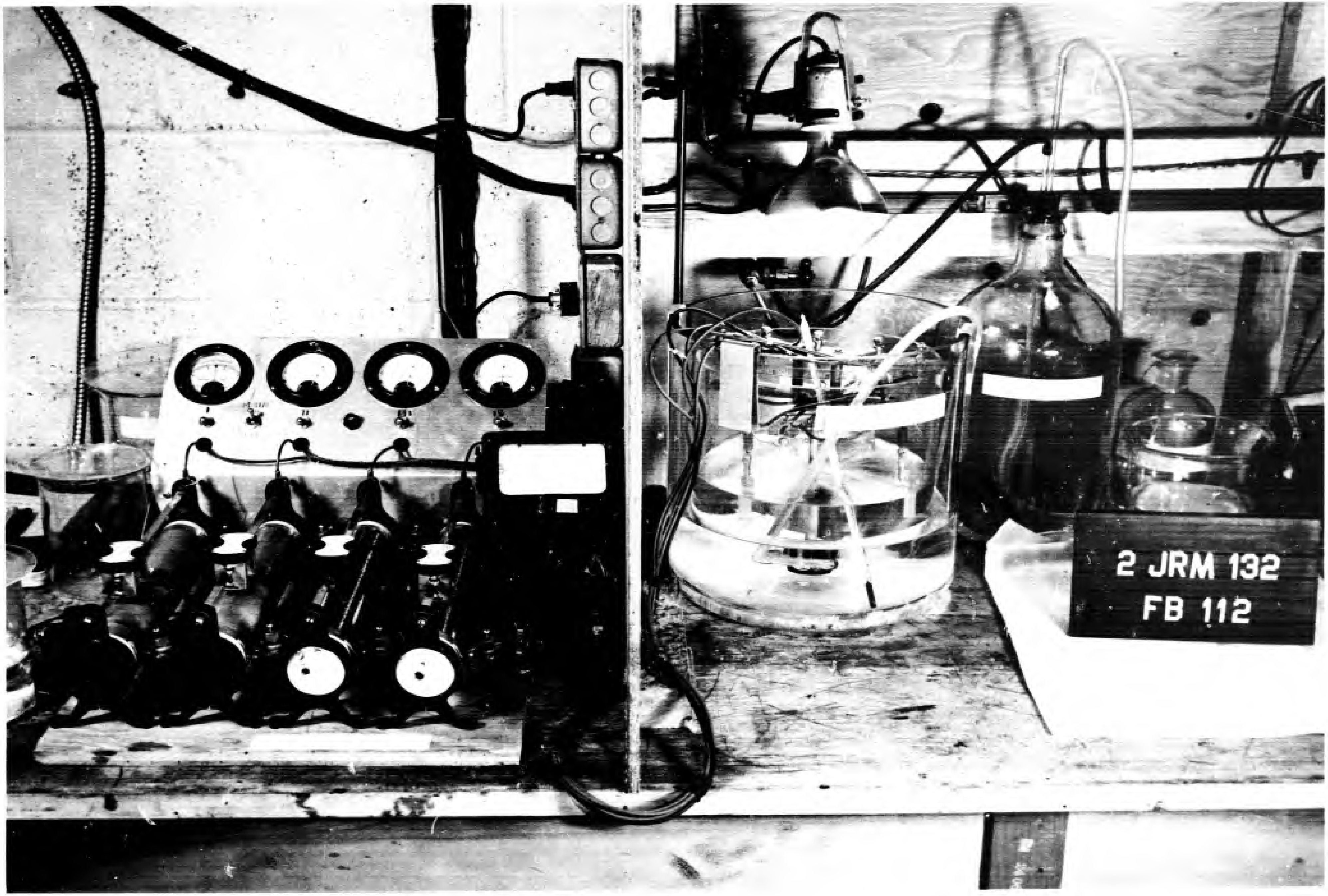

2 JRM 132
FB 112

Photo No. FB297

Title Secondary Emmission Testing

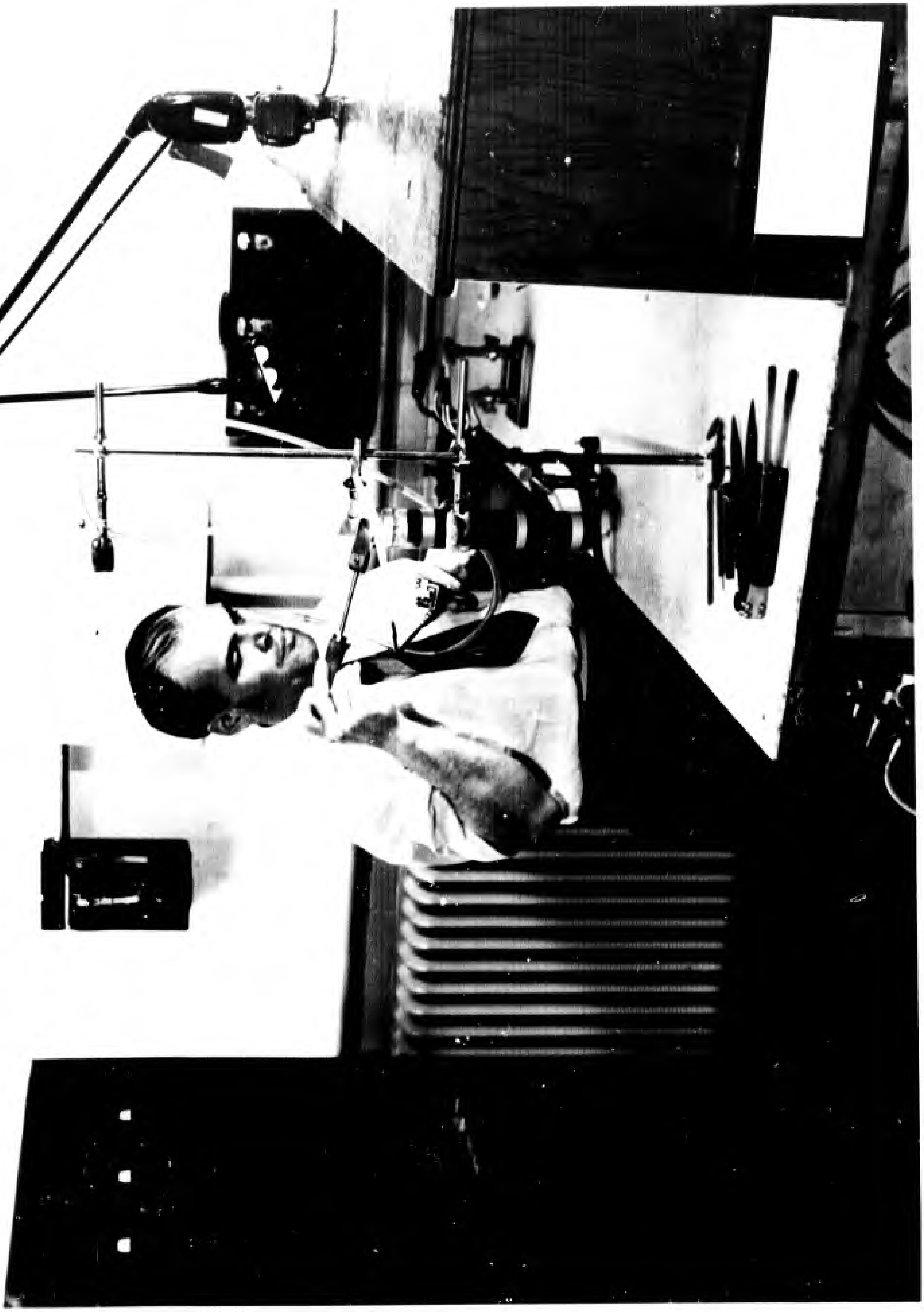
Special tubes are constructed for investigation of secondary emmission phenomona and ageing. One such tube is shown installed in a test set-up in the center of this photograph.


DANGER
FB297

Photo No. FB197

Title Glass Blowing Bench and RF Bomber

The tube construction laboratory is equipped for the construction of experimental tubes and for the production of the quantity of storage tubes needed for Whirlwind I. This photograph shows work proceeding on the construction of a special tube using the glass blowing bench. At the left is a 45 kilowatt input General Electric RF Bomber.



FB-197

Photo No. FB293

Title Vacuum Systems

Two vacuum systems complete with ovens and measuring equipment are available for the construction of future tubes. In the past, facilities available in the M. I. T. Research Laboratory for Electronics shops have been used.

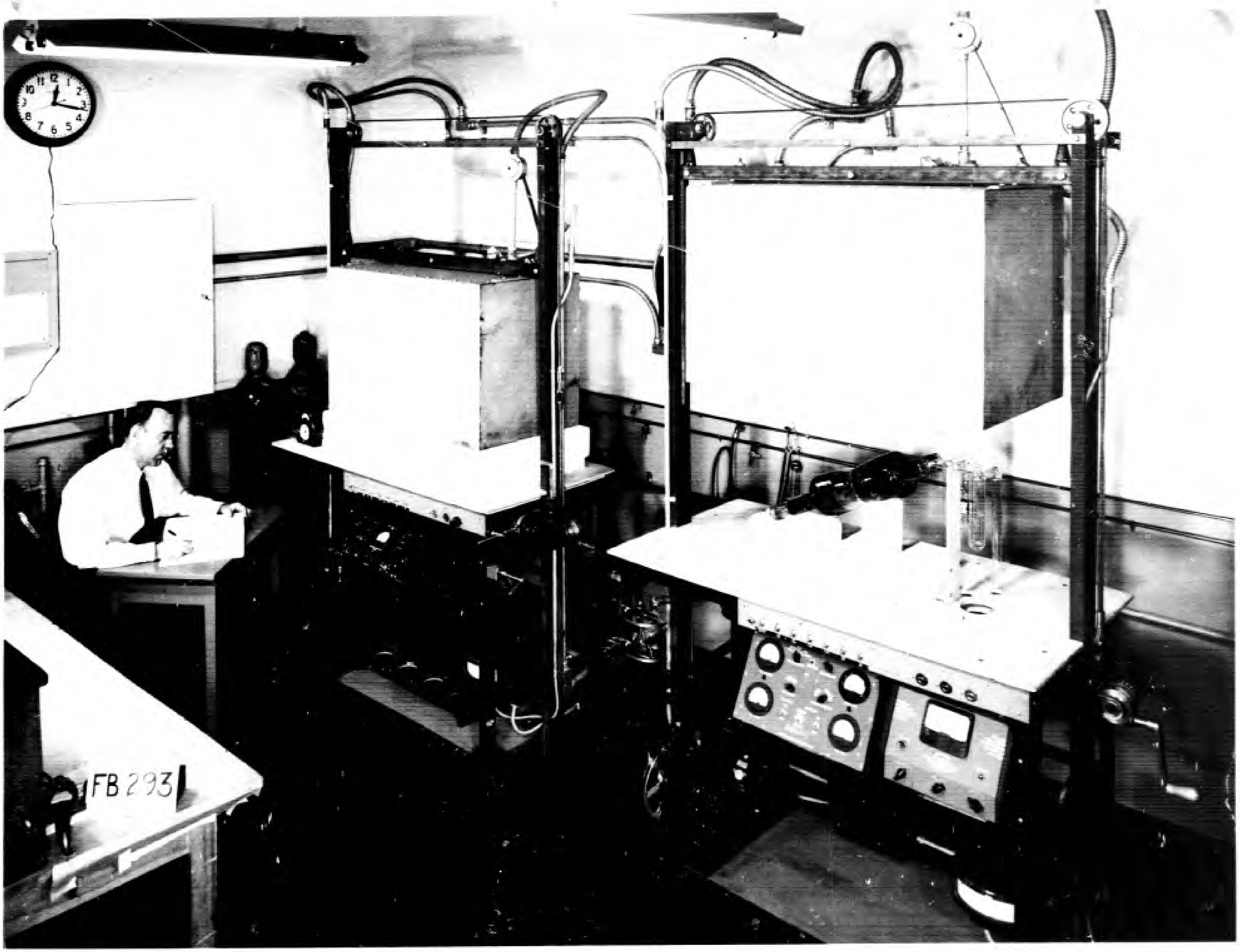
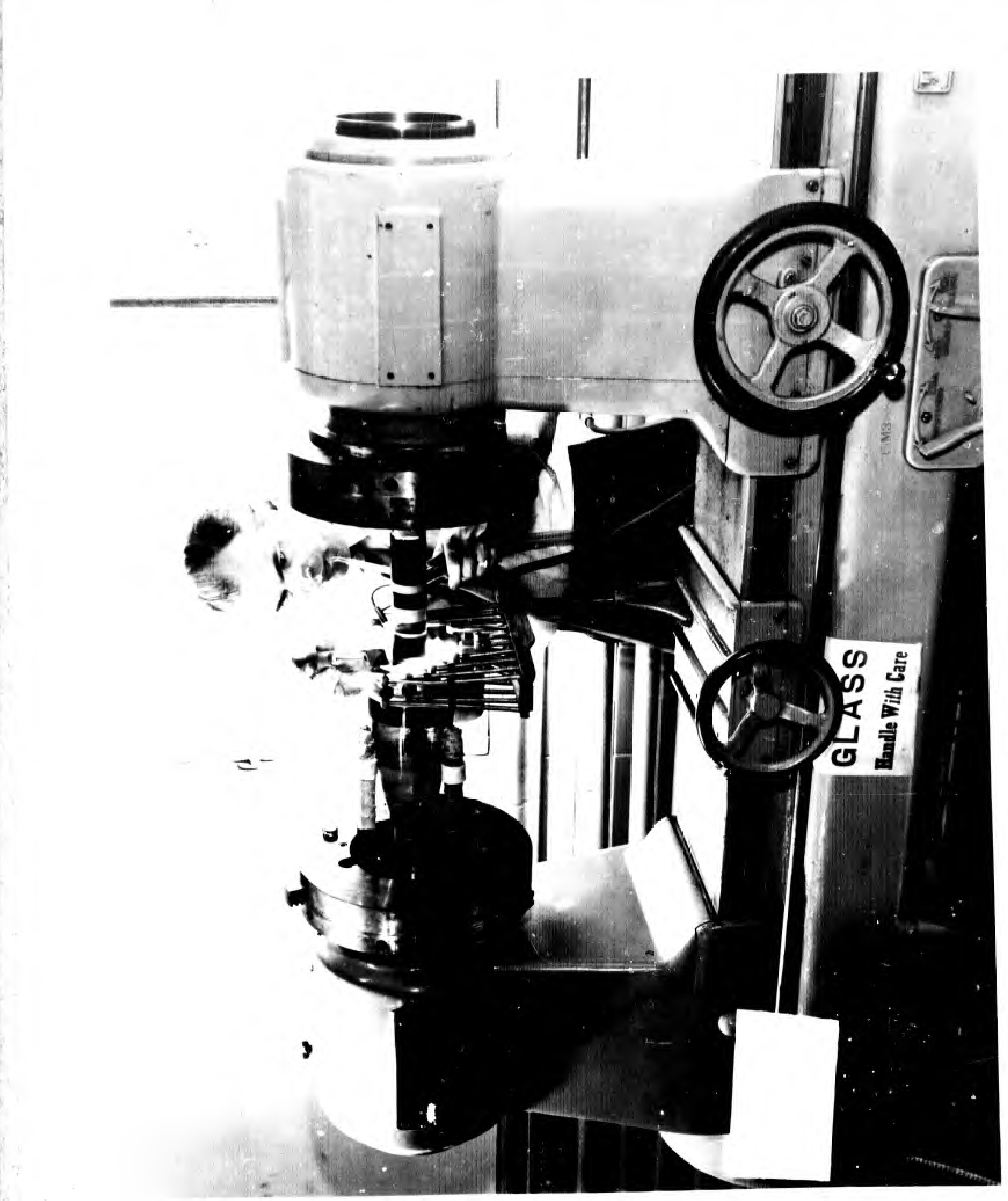

FB 293

Photo No. FB194

Title Glass Lathe

A glass lathe, important for tube construction, is shown in this photograph. Both headstock and tailstock revolve. The lathe is being used for the joining of glass cylinders.



FB—194

Photo No. FB296

Title Storage Tube Test

Specialized equipment has been developed and built for the tests on storage tubes. With the equipment shown in this photograph, it is possible to write positive or negative signals on preselected parts of the storage surface with various amplitudes and durations of writing signals, to read out positive and negative signals and measure the read time, amplitude, and shape of the output signal, and to determine permanence of stored signals and other factors necessary to a complete study of the behavior of storage tubes.


DANGER
DANGER
DANGER
HIGH VOLTAGE

10.5 Staff List

Jay W. Forrester	B.S. in E.E. S.M. in E.E.	Nebraska M.I.T.	1939 1944
Samuel R. Abbott	B.S. in E.E.	Worcester Poly.	1939
Richard L. Best	B.E.E.	Cornell Univ.	1943
Edwin I. Blumenthal	B.S. in E.E.	Tufts College	1947
William C. Bohn	S.B. Physics	Harvard	1925
Hugh R. Boyd	M.A. Education	Wayne Univ.	1940
David R. Brown	S.M. in E.E.	M.I.T.	1947
Charles H.R. Campling	B.S.	Queen's Univ.	1944
David J. Crawford	S.M. in E.E.	M.I.T.	1947
Michael Daniloff	M.S.	Harvard	1931
Normal L. Daggett	S.B. in E.E.	M.I.T.	1947
Stephen H. Dodd, Jr.	S.M. in E.E.	M.I.T.	1943
Carleton G. Eaton	B.S. in E.E.	M.I.T.	1943
John O. Ely		Texas Tech and M.I.T.	
Robert R. Everett	S.M. in E.E.	M.I.T.	1943
Harris Fahnestock	A.M.	Harvard	1930
Alfred M. Falcione	B.S. in E.E.	Tufts College	1935
Mark Flomenhoft	B.S. in E.E.	Univ. of Penn.	1943
Margaret I Florencourt	A.B. Physics	Radcliffe College	1946
Philip Franklin	PhD.	Princeton Univ.	1921
George G. Hoberg	B.E.E.	Villanova College	1945
Arthur B. Horton, Jr.	S.B. in E.E.	M.I.T.	1946
Harry Kenosian	S.B. in E.E.	M.I.T.	1947

William K. Linvill	S.B. in E.E.	M.I.T.	1945
Robert L. Massard	B.S. in E.E.	Univ. of Chicago	1945
Joseph H. McCusker	B.S. in E.E.	Northeastern Univ.	1947
Howell B. Morley			
William J. Nolan, Jr.	B.E.E.	R.P.I.	1940
John A. O'Brien	B.S.	Univ. of Maine	1943
John J. O'Brien	A.B.	Boston College	1945
John C. Proctor	B.S.	M.I.T.	1938
Edward S. Prohaska	A.B. in M.E.	M.I.T.	1935
Edgar Reich	B.E.E. in E.E.	Poly. Inst. of Brooklyn	1947
Edwin S. Rich	B.S. in E.E.	Univ. of Maine	1940
Chester A. Rowland, Jr.	B.S. in E.E.	Iowa State	1945
Eugene A. Sard	S.B. in E.E.	M.I.T.	1944
Richard Shaw, Jr.	M.S.	M.I.T.	1934
Joel M. Simmons, Jr.	B.S.	Texas Tech.	1947
George C. Sumner	B.S. in E.E.	Texas Agric. and Mech.	1942
Francis E. Swain	M.S. in E.E.	Univ. of Colorado	1933
Norman H. Taylor	B.S.	Bates College M.I.T.	1937 1939
Joseph N. Ulman, Jr.	A.B. B.E.	John Hopkins Univ. John Hopkins Univ.	1928 1934
Chauncey W. Watt, Jr.	B.S.	Calif. Inst. of Tech.	1936
C. Robert Wieser	M.S.	M.I.T.	1940
Patrick Youtz	S.M.	Univ. of Chicago	1929

10.6 Machine Tools and Equipment

Machine Tools

1 - South Bend Lathe with 13" swing and 5' bed and accessories

1 - South Bend Lathe with 10" swing and 4' bed and accessories

1 - Whitney-Jensen Punch Press (hole punches 1/2 to 2-1/2 inches, square punches 1 to 2 inches)

1 - Bridgeport Vertical Milling Machine Model 4679

1 - Burke Milling Machine Model 126A

1 - Craftsman Drill Press (1/2 inch max.)

3 - Delta Drill Presses (1/2 inch max.)

1 - Delta Drill Press (1 inch max.)

1 - Peck, Stow and Wilcox Shear (18 gauge stock, 52" bed)

1 - Chicago Steel Bending Brake (48" bed with 11 adjustable fingers)

1 - Delta Milwaukee Band Saw (45° tilting table with 13" bed)

1 - Walker Turner Sanding Machine (48" sanding belt and 10" sanding wheel)

1 - United States Electrical Tool Grinder (drill sharpening attachment)

1 - Delta Milwaukee Jig Saw, Type SOS

Oscilloscopes and Synchroscopes

2 - Browning P4E Synchroscopes

6 - Dumont Model 208 Oscilloscopes

1 - Dumont " 224A "

1 - Dumont " 241 "

3 - Dumont " 256A/R Rangescopes

2 - RCA " 160B Oscilloscopes

5 - Western Electric TS-239/UP Oscilloscopes

6 - Signal Corps TS-34 Oscilloscopes

12 - Sylvania Model 5 Synchroscopes

2 - Sylvania P-4 Synchroscopes

Vacuum Tube Voltmeters and Multitesters

9 - Ballantine Voltmeters (Model 300-A)

1 - Ballantine Voltmeter (Model 304)

3 - Ballantine Decade Amplifiers (Model 220)

4 - Ballantine Decade Multipliers (Models 402A and 402B)

4 - Boonton High Frequency Voltmeters (No. 62)

4 - Hickok Multitesters (Model 202NX)

2 - Radio City Multimeters (Model 662)

5 - RCA Voltohmysts (Model 164)

12 - RCA Voltohmysts (Model 195)

4 - Sylvania Polymeters (No. 134)

Signal Generators and Counters

2 - Dane Pulse Generators

1 - Hewlett Packard Audio Oscillator (No. 200CR)

1 - Hewlett Packard Oscillator (No. 205AG)

1 - Hewlett Packard Oscillator (No. 200I)

1 - Hickok Signal Generator (Model 188X)

1 - Millen Signal Generator (No. 9050)

4 - USN Model LP-5 Signal Generators

6 - GE Decade Counters (Type YYZ-1)

Non-Elelectronic Voltmeters and Multitesters

49 - Simpson Multimeters (No. 260)

2 - Weston Multimeters (No. 772)

Test Equipment Designed and Constructed by this Project

12 - Variable Frequency Clock Pulse Generators
Pulse width - .05µs; PRF 0.88 to 6.2 MC

1 - Variable Frequency Clock Pulse Generator
Pulse width - variable from 0.2 to 0.3 µs;
PRF 0.85 to 1.5 MC

1 - Crystal-controlled Clock Pulse Generator
Pulse width variable from 0.2 to 0.3 µs;
PRF 1 MC

12 - Restorer Pulse Generators
Paired pulses are 0.1 µs wide, 1µs apart at
a PRF of 100 kc; 1 µs synchronizing pulse at
100 kc; single push-button controlled pulse
0.1 µs wide, synchronized with 100 kc output

5 - Binary Frequency Dividers
Frequency Division of 2:1, 4:1;
Output pulse 0.1 μs wide

10 - Gate and Delayed Trigger Generators
Provide either a gate whose width is continuously variable from 3 to 2500 μs, or a trigger whose delay is continuously variable from an input trigger by the same amount.

7 - Gas Tube Pulse Generators
Provide a rectangular pulse whose width is continuously variable from 0.05 to 1 μs at repetition frequencies up to 4 kc.

1 - Clock-restorer Pulse Distributor
Takes 1MC pulse, gates two successive pulses through one channel, and gates the remaining eight pulses through another channel.

General Test Equipment

1 - Boonton "Q" Meter

2 - Elgin Stop Watches

1 - GE Galvanometer

1 - General Radio Wave Analyzer

1 - General Radio Capacitance Bridge (No. 740BG)

1 - General Radio Strobotac

1 - Hickok Tube Tester (No. 532)

1 - Leeds and Northrop Resistance Box (Type 4750)

1 - Navy TS-102A Calibrator

8 - Rawson Precision Thermal Meters
(Models 501, 511, and 522)
(1/4 - 1/2%)

1 - Shallcross Percent Limit Bridge (No. 617N)

11 - Simpson Multirange Testers (Nos. 280-3-6-7)

3 - Triplett Multirange Testers (No. 670)

4 - Weston A.C. Meters (No. 433)

6 - Weston D.C. Meters (No. 425-30)

1 - Weston Precision Voltmeter (Model 341)

Miscellaneous Equipment

1 - Brown Electronic Potentiometer

2 - Cyclotron Impulse Registers

20 - C-D Decade Capacitors (Model CD)

1 - GR Decade Capacitor (No. 219)

6 - GR Decade Resistors (No. 602)

1 - Mico Engraver (No. 251)

2 - Shallcross Decade Potentiometers

Power Supplies

1 - AAC High Voltage Power Supply (Type RA-58H)

60 - Radiation Laboratory Power Supplies (P-1)

20 - Radiation Laboratory Power Supplies (P-3)

18 - Raytheon Power Supplies (No. WX-5013H)

5 - Raytheon Rectichargers (No. W-5752)

33 - USN Power Supplies (Model CW 20AAE)

Photography and Projection

1 - Argus Model C-2 Camera with hood and lucite scale for general oscilloscope work

1 - Special oscilloscope camera using Zeiss F1.4 lens for oscilloscope single trace work

2 - Eastman 35-mm Kodaslide Projectors

1 - Eastman Recordak Projector

1 - Bressler - 3" x 4" Slide Projector

1 - Graflex 4" x 5" Camera with commercial Ektar and wide-angle lenses

1 - Simmons 4" x 5" Omega Enlarger with 3" and 6" lens

1 - Pako Print Dryer

1 - Print Washer

Lights, tripods, timers and similar required equipment

Vacuum System Equipment

2 - Special design vacuum systems having the following features:

a. Welch (1405H) Fore Pumps

b. DPI 3-stage Diffusion Pumps

c. 10K.W. Winch-operated Ovens (controlled to any temperature up to 600°C by Capictrol controllers)

d. McLeod Calibration Gauges

1 - National Research Ionization Gauge (No. 706)

1 - National Research Alphatron Vacuum Gauge (No. 510)

1 - DPl Vacuum Gauge (No. HG-200)

1 - GE 45 K.W. Induction Heater

1 - Litton Glass Lathe (Model K)

1 - 5 K.W. Spot Welder

1 - Glass-working Bench and Accessories

1 - Anodizing Bench with Required Control and Test Equipment

1 - Bausch and Lomb Shop Microscope (x 100)